Roadmap Update for Natural Gas Infrastructure Reliability

January 29-30, 2002

Workshop Proceedings

U.S. Department of Energy
Office of Fossil Energy
National Energy Technology Laboratory

Roadmap Update for Natural Gas Infrastructure Reliability

WORKSHOP PROCEEDINGS

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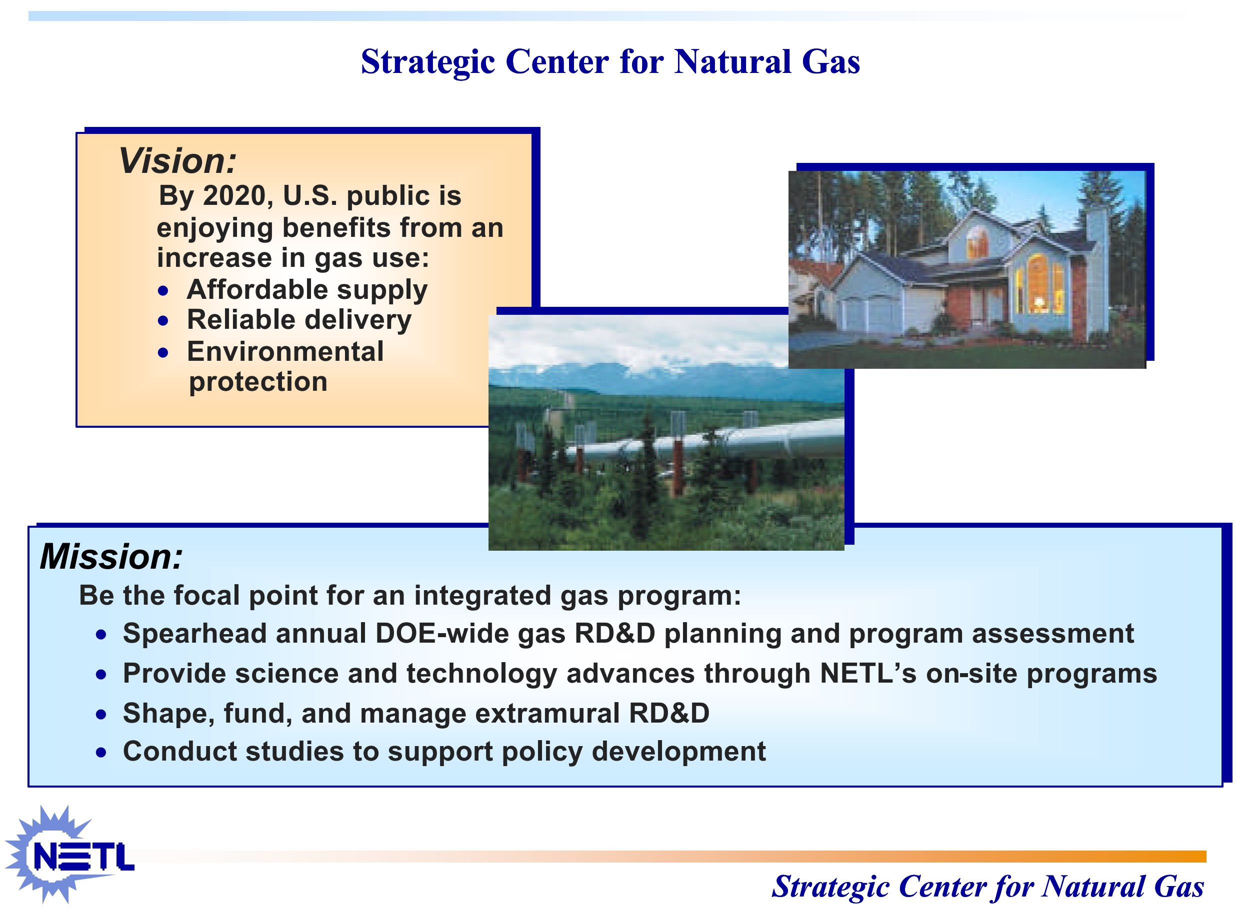
SECTION 1.0

INTRODUCTION

A. OVERVIEW

The Strategic Center for Natural Gas (SCNG) of the DOE's National Energy Technology Laboratory (NETL) sponsored a two-day workshop in Pittsburgh, Pennsylvania on January 29-30, 2002. The purpose of the workshop was to gather stakeholder input on research needs and opportunities, provide feedback regarding the program's current project portfolio, and to assist in updating the Natural Gas Infrastructure Reliability Roadmap. This workshop served as a forum to bring together members of the infrastructure industry to focus on innovative technology solutions.

This document presents the proceedings of the workshop. These include a summary of the workshop's products, the plenary presentations of the DOE hosts, the detailed products of three work-groups, and participant views of how resources would best be allocated over research topics and timeframes.



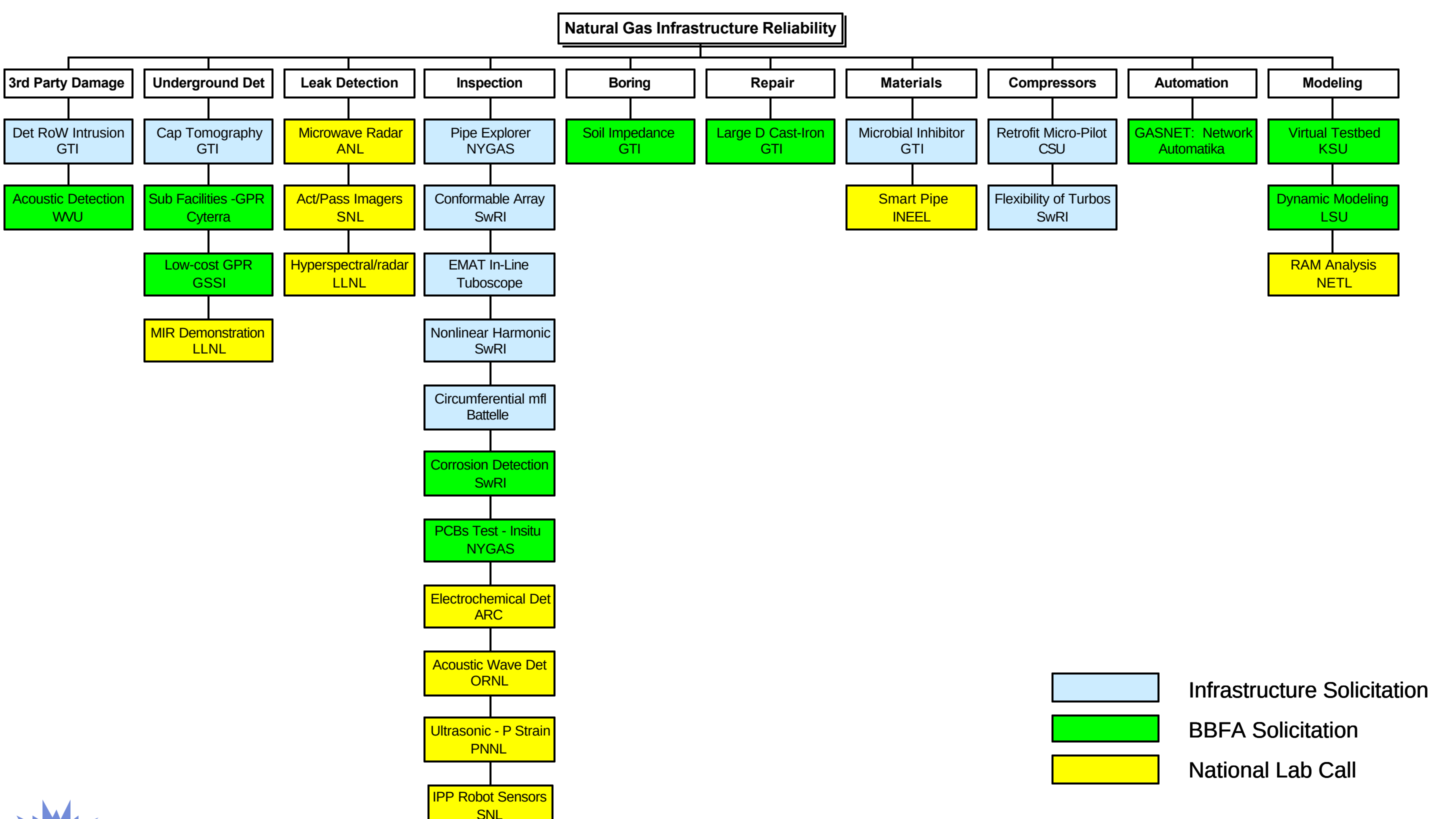
B. BACKGROUND

In mid-2000, NETL held two industry workshops to gather input for an infrastructure roadmap. Based on this framework, the program selected a portfolio of projects through competitive solicitations to support roadmap implementation. The current portfolio has 31 projects, selected from three procurement actions: a targeted solicitation for gas infrastructure, a broad-based financial assistance (BBFA) solicitation, and a National Laboratory call for proposals.

Since this time, many new developments have occurred including the recent emphasis on infrastructure security. Input was needed to ensure that the roadmap and the portfolio of projects are adequately representing the needs of the industry and are positioned to best use the government's role for public interest. Participant input from this workshop will be used to assure the best opportunities for program support are identified and pursued, thus enhancing the public benefits of R&D innovation for assured deliverability.

Most natural gas consumed in the United States is not produced in the areas where it is most needed. To get gas from increasingly remote production sites to consumers; pipeline companies operate and maintain more than 300,000 miles of main transmission lines. This gas is then sold to local distribution companies (LDCs) who deliver gas to consumers using a network of more than 1,000,000 miles of local distribution lines. In total, this vast underground transmission and

Project Portfolio



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distribution (T&D) system is capable of moving 131 billion cubic feet (bcf) of gas each day. To provide force to move the gas, and to improve the economics of gas transportation, operators install large gas-powered compressor stations spaced roughly 100 miles apart along each pipeline. Despite this enormous infrastructure of pipes and compressors, and the increasingly long distances that much of the gas travels, the T&D network has proven to be incredibly safe, reliable, and efficient.

However, several emerging issues indicate a clear need for federal action to ensure the continued sound performance of the T&D system. First, the security and assurance of our nation's infrastructure has taken a high priority position in homeland security. The recent events in our country require that a new angle to security and T&D assurance be considered. Second, natural gas demand is expected to grow rapidly in the coming decades, and could quickly exceed the current system capacity. Furthermore, the traditional seasonal pattern of gas use is changing; as much as 50% of new gas demand over the next 20 years is expected to fuel the generation of electricity. This expanded role for gas will increase demand during the summer months – a period when the industry traditionally stockpiles gas for the winter. Third, recent changes in natural gas markets raise serious questions about who's looking out for the public good. Restructuring, designed to increase industry competitiveness, has forced companies to focus on short-term cost-cutting. As a result, there is a growing lack of R&D of new technologies that will allow the system to safely and efficiently serve expanding future markets.

Reliability of the T&D system is essential to assure the availability of affordable, clean energy for our nation's homes, businesses, and industries. A number of factors, including an aging infrastructure, increasing demand, deregulation and restructuring, as well as intense competition are putting stress on the existing infrastructure and threatening the reliability of the gas infrastructure systems. Reduced industrial R&D further contributes to the long-term uncertainty. Therefore, with much of the system running at full utilization, and key industries (such as electric power generation) becoming more reliant on natural gas, the future of the gas transmission and distribution system must be addressed to ensure the public welfare. To address these needs, the DOE, through the SCNG, has initiated an Infrastructure Reliability Program to support the SCNG's mission to "look out for the future of gas – from borehole to burnertip." The program's primary goal is to foster the technologies needed to ensure the reliability, efficiency, and safety of the nation's critical gas distribution network as it adapts to rapidly-changing natural gas markets. The program focuses on the following specific goals.

- ***Enable Cost Reduction***: Allowing the gas pipeline system to operate, maintain, and expand more quickly and efficiently.
- ***Ensure Reliability***: Allowing operators to prevent damage or disruption, to detect and diagnose leaks and failures more quickly, and to enhance the flexibility and responsiveness of the system in response to losses in capacity.
- ***Improve System Efficiency***: Providing analytical tools that can support day-to-day operations and predict future bottlenecks and needed capacity additions. In addition, technology development and regulatory efforts may allow an increase in capacity of existing pipelines.
- ***Protect the Environment***: Fostering new technologies that result in a reduction in pipeline leaks and a reduction in the rate of compressor air emissions. Export of U.S. technologies

and practices to reduce the enormous volumes of methane leaking from foreign pipeline systems will be a key goal of the program.

- ***Secure the Infrastructure***: Developing advanced technologies that allow early detection of intrusions or attacks, and providing new tools for mitigating damage and speeding recovery.

NETL is working closely with all portions of the gas industry, from gas suppliers to end users, to identify operational factors which effect reliability and to implement R&D efforts to maintain the high levels of reliability the U.S. public is accustomed to receiving. NETL will work with industry, universities, and national laboratories to develop advanced technologies and systems that provide improved pipeline integrity.

C. WORKSHOP PROCESS AND PRODUCTS

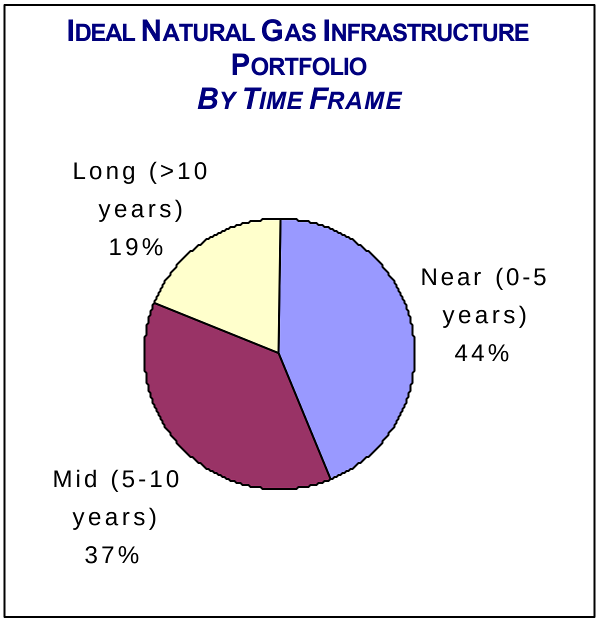
As the workshop's purpose was to gather stakeholder input on the current research portfolio, presentations during the plenary session presented an overview of the Natural Gas Infrastructure Reliability Program and a snapshot of the 31 projects currently in the portfolio. Participants then worked in one of three work groups that ran in parallel sessions. The three workgroups:

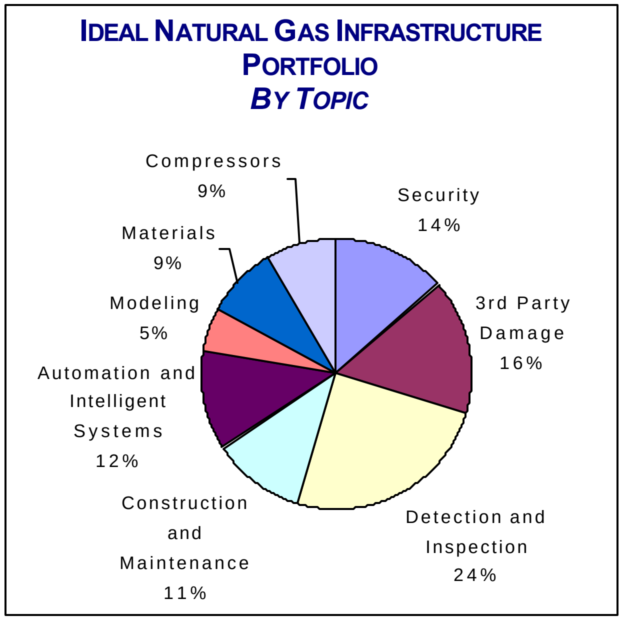
- ***Infrastructure Security and Energy Assurance***. This group focused on the technology opportunities that can augment or supplant traditional methods and tools for infrastructure security. Participants in this group focused on the development of new, advanced technologies that address energy security. Topics included, for example, sensors and monitoring systems, enhanced durability components and systems, and improved data acquisition and analysis.
- ***R&D Innovations Group***. This group focused on technology innovations that could be integrated into current systems within the next five years and on entirely new systems, approaches, and materials that could revolutionize infrastructure systems over the next 20 years or more. Topics covered the entire infrastructure life cycle of design, construction, operation, and maintenance. Near-term topics included, for example, technologies whose current development processes could be accelerated and/or technologies that could be adopted or adapted from other industries and integrated as a component of or enhancement to current systems.
- ***Interdependencies, Modeling, and Integration***. This group focused on the growing national and regional interdependencies between energy infrastructures that have the potential to expand reliability concerns from gas to the entire energy infrastructure. Topics included, for example, modeling, system diagnostics and controls, improved information flow and communications, resource and information sharing, and the interdependencies between natural gas infrastructure and electrical infrastructure.

Each of the three parallel sessions functioned as facilitated workgroups. In each group, the participants brainstormed and analyzed key barriers, the current research portfolio, and R&D opportunities. They also developed action plans for the high-priority R&D topics selected by the group. During the course of the day and a half workshop, participants identified five sets of information:

- Key barriers and issues to infrastructure reliability: barriers included regulatory, market, policy, security, and institutional factors as well as technology issues.
- R&D opportunities to overcome these issues: opportunities included both technology development and other necessary conditions for success.
- Gaps in the current portfolio of projects: feedback was needed to ensure that the portfolio is representative of the needs of the industry.
- Implementation plans to attain the goals: for high-priority areas of opportunity, participants identified requirements; R&D products, elements, and specifications; critical items and/or steps; leaders and collaborations; and schedule and funding.
- Allocation of portfolio resources: participants independently identified how they thought R&D resources should be allocated in an "ideal" portfolio according to (1) time frames and (2) research topics. Participants voted by allocating hypothetical resources in 10% increments, the results are shown below.

Section 2.0 presents the plenary presentations, and Section 3.0 presents the work-group products.





SECTION **2.0**

PLENARY SESSION: PRESENTATIONS

This section provides the presentations give by DOE/NETL Infrastructure Reliability Program representatives during the workshop's plenary session. These presentations were used to provide background to the workshop participants about the program, work to date, and the current portfolio of projects.

A. WELCOME/OVERVIEW & INFRASTRUCTURE ROADMAP
Rodney Anderson, Product Manager, Infrastructure Reliability
National Energy Technology Laboratory

B. DOE INFRASTRUCTURE RELIABILITY PROGRAM PORTFOLIO REVIEW
Daniel Driscoll, Project Manager, Gas Supply Projects Division
National Energy Technology Laboratory

A. WELCOME/OVERVIEW & INFRASTRUCTURE ROADMAP

Rodney Anderson, Product Manager, Infrastructure Reliability
National Energy Technology Laboratory

Natural Gas Infrastructure Reliability

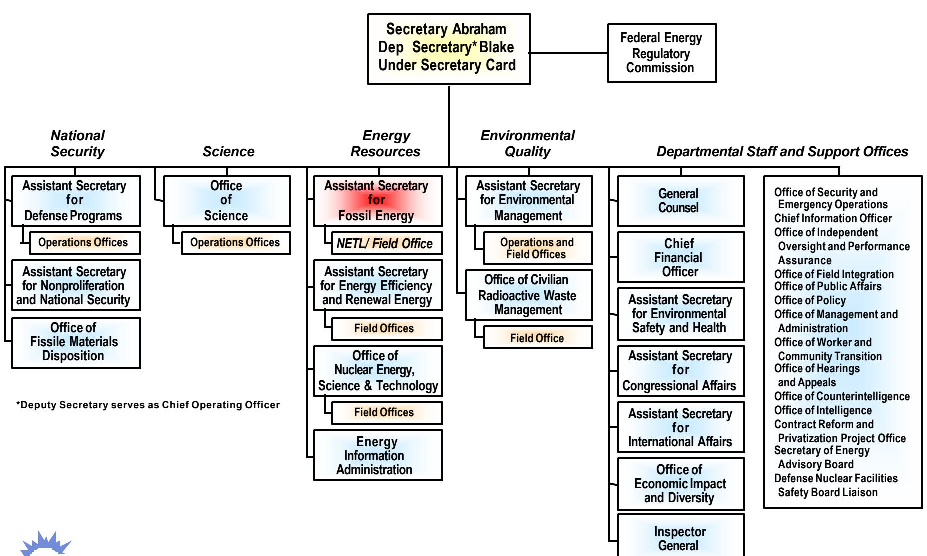
Roadmap Update
January 29 - 30, 2002

Pittsburgh, PA

Dr. Rodney J. Anderson
Product Manager

Strategic Center for Natural Gas

Department of Energy



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What NETL Is

Industry Focussed

What We Are

One of DOE's 15 National Laboratories: December, 1999

Government Owned and Operated

Morgantown, WV, Pittsburgh, PA, and Tulsa, OK

What We Do

Shape, fund, and manage extramural RD&D programs

Conduct on-site science and technology research

Conduct analyses to support policy development

Mission

Provide Americans with a stronger economy, healthier environment, and more secure future by resolving the environmental, supply, and reliability constraints of producing and using fossil resources

- Nearly 700 research activities in all 50 states and 16 countries
  - Private Industry
  - Universities/colleges
  - Not-for-profit laboratories
  - DOE National Laboratories
  - Other government laboratories

- *Strategic Center for Natural Gas*

- 550 Federal Employees
  - Technical Management
  - In-House R&D
  - Administration
  - E&E technical & business services

- FY01 Budget of $722 Million

- 608 Support Contractors
  - 480 On-Site
  - 128 Off-Site

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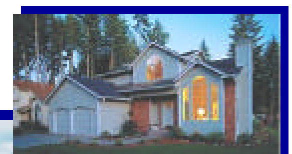
Vision:

By 2020, U.S. public is enjoying benefits from an increase in gas use:

- Affordable supply
- Reliable delivery
- Environmental protection



Mission:

Be the focal point for an integrated gas program:

- Spearhead annual DOE-wide gas RD&D planning and program assessment
- Provide science and technology advances through NETL's on-site programs
- Shape, fund, and manage extramural RD&D
- Conduct studies to support policy development

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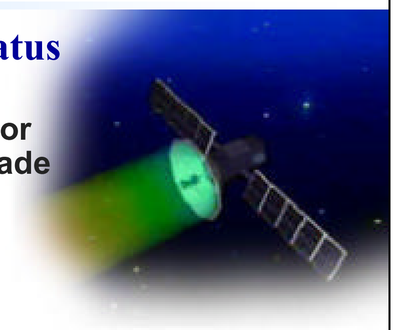
Technology Status



- **Beginning of 20th Century: All major scientific discoveries had been made**
  - Television
  - Internet
  - Nuclear power
  - Space
  - Wireless communications using satellites

- **Beginning of 21th Century:**
  - Teleportation?
  - Computers and electronic based on new concepts?
  - New sources of energy – cold fusion?

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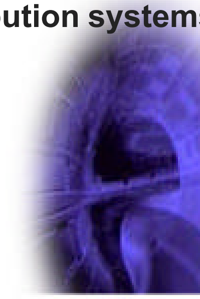
Natural Gas Infrastructure Future

- **Compressors with no moving parts**
- **Smart pipes that 'feel', 'talk', and 'heal'**
- **Robots that live in pipes**
- **Remote monitoring network: leaks & intrusions**
- **Intelligent pipeline/distribution systems**



- **Hydrogen?**

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FY01 Infrastructure Activities

Goals
Elicit stakeholder input
- Vision
- Technology needs & opportunities

Determine government role

Interagency Workshop
March 22 & 23, Washington, DC
DOE, DOT, FERC, EPA, DOI

Visioning Workshop
May 3, Pittsburgh, PA
15 industry executives

Roadmapping Workshop
June 6 & 7, St. Louis, MO
40 industry experts

National Lab Call
9 Projects Selected
Multiple Labs
Focus on Innovation

Competitive Solicitation
11 Projects Selected
Multiple awards
Various stages of development

Broad-Based Financial Assistance
10 Projects Selected
Multiple Awards
Various stages of development

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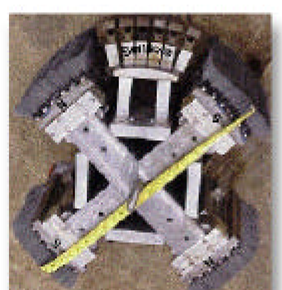
FY02 Plans

- **Update Natural Gas Infrastructure Roadmap (January)**
- **Release new solicitation based on revised roadmap (March)**
  - Gaps, energy assurance, & innovations
- **Integrate security into program**



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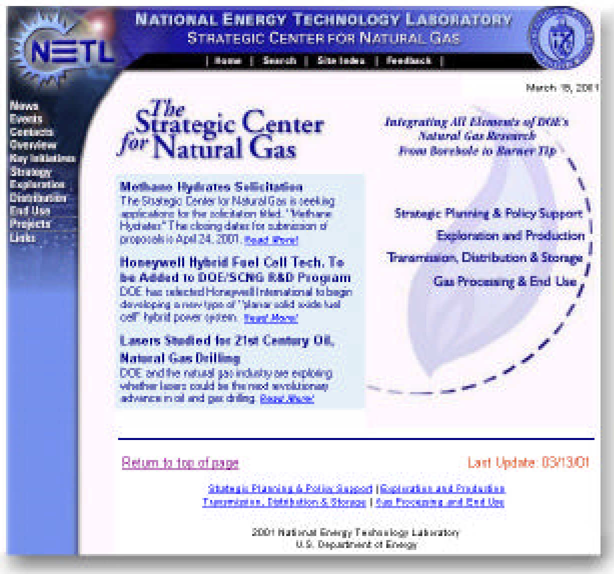

Internet Location: **netl.doe.gov/scng/index.html**

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B. DOE Infrastructure Reliability Program Portfolio Review

Daniel Driscoll, Project Manager, Gas Supply Projects Division
National Energy Technology Laboratory

Natural Gas Infrastructure Reliability

Natural Gas Infrastructure Reliability

January 29, 2002

Dr. Dan Driscoll

Mr. Ron Harp

Project Manager

GSP Division

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Gas Infrastructure Reliability

- **New DOE Initiative that builds on NETL's existing gas storage program**
- **Infrastructure includes: transmission, distribution & storage**
- **Program goals are:**
  - Maintain/enhance system reliability and integrity
  - Increase gas deliverability
  - Reduce environmental impact
  - Address interdependencies between gas & electric systems
  - Develop technological foundation for future gas delivery system
  - Support infrastructure security
- **FY01/FY02 Budget: ($8 million/$10 million)**
  - $3 million /$2.5 million storage technology
  - $5 million /$7.5 million infrastructure systems reliability

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Infrastructure History/Status

- Mid FY00 - Program Initiated - No funding, No Projects
- October FY01 - Initial Funding ($4,950K)
- September FY01 - 31 Projects ($17,000,000)
- October FY02 - $7,500K
- January FY02 - Technology Status Assessments
- March FY02 - Second Solicitation

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FY01 Infrastructure Activities

Goals
Elicit stakeholder input
- Vision
- Technology needs & opportunities

Determine government role

Interagency Workshop
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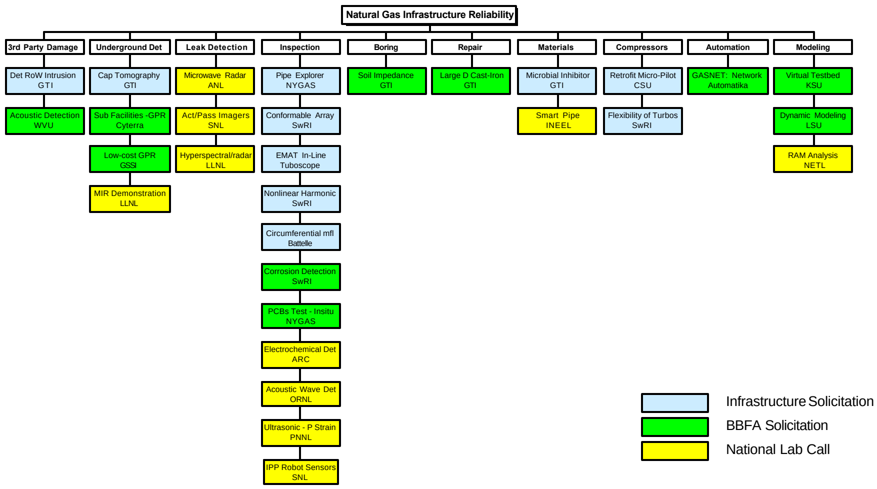
Project Portfolio



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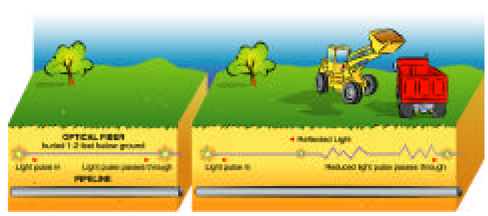
- **Title:**
  - Detection of Unauthorized Construction Equipment in Pipeline Right-of-Ways
- **Description:**
  - Develop and demonstrate an optical fiber intrusion detection device that will prevent outside force damage by detecting and alarming when construction equipment is near a natural gas pipeline.
- **Partners:**
  - Nicor Technologies (IL)
  - Nicor Gas (IL)
  - Gas Research Institute (IL)



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West Virginia University

- **Title:**
  – Acoustic Detecting and Locating Gas Pipeline Infringement

- **Description:**
  – This project will develop a system to detect the unique sound wave generated when a pipeline break releases a large discharge of gas after being damaged by landslides, excavations, or other disturbances. The system will be designed to monitor the background noise inside the pipe and pick up any sudden new frequencies that might signal a sudden pipeline rupture.

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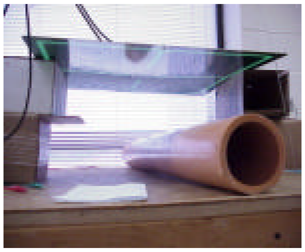
Gas Technology Institute



- **Title:**
  – Capacitive Tomography for the Location of Plastic Pipe

- **Description:**
  – A compact, low cost system for subsurface imaging of plastic and metallic objects utilizing capacitive sensing techniques. Thin-film capacitive tomography imaging sensors may also be applied to digging and boring tools to detect obstacles.

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CyTerra Corporation

- **Title:**
  - Detection of Subsurface Facilities Including Non-Metallic Pipe
- **Description:**
  - A portable, low-cost, real-time, and user-friendly pipe and utility line detector. Adaptation of a unique shallow buried plastic target detection technology developed for the US Army.

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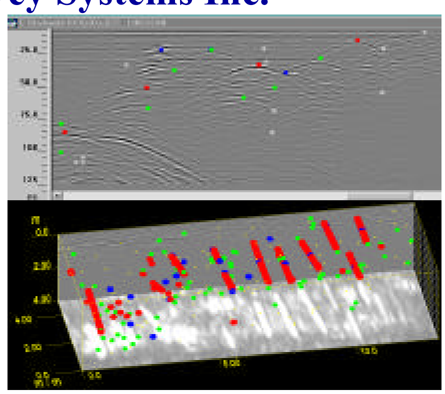
Geophysical Survey Systems Inc.



- **Title:**
  - A Low-Cost GPR Gas Pipe and Leak Detector
- **Description:**
  - A low-cost, easy-to-use, Ground Penetrating Radar (GPR) for locating metallic and non-metallic gas pipelines, as well as the remote detection of pipeline leaks.

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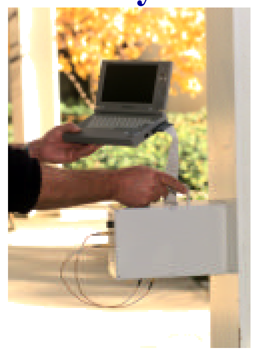
Lawrence Livermore National Laboratory



- **Title:**
  – Micro-Power Impulse Radar (MIR) Demonstration for Pipe/Facilities Locator
- **Description:**
  – A low power, compact, ultra-wide band radar technology that is well suited for battery operated handheld radar sensing applications. This project will test and demonstrate several MIR units suitable for locating underground pipes and other facilities, including plastic pipes and fiber optic cables.
- **Partners:**
  – New York Gas Group

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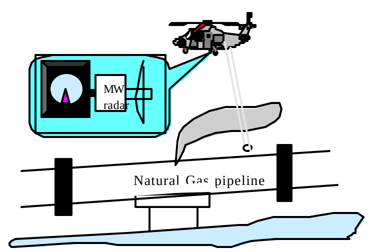
Argonne National Laboratory



- **Title**:
  – Microwave Radar Sensing of Gas Pipeline Leaks
- **Description**:
  – This project will develop and field test a pulsed microwave radar imaging system to detect and locate gas leaks from above or underground natural gas pipelines. The system can be mounted on a vantop or fitted on an aircraft for fast mapping of natural gas leaks.

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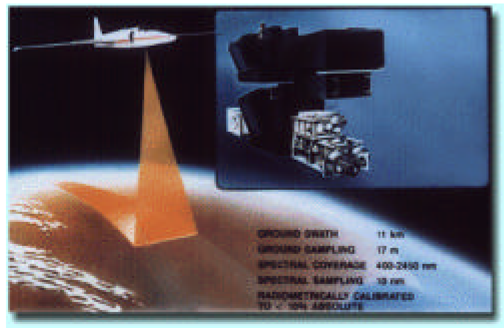
Sandia National Laboratory

- **Title**:
  - Active and Passive Gas Imagers for Transmission Pipeline Remote Leak Detection



- **Description**:
  - Evaluate the application of emerging active (laser-illuminated) and passive (thermal emission) imaging and mapping approaches to detect gas leaks remotely, on both airborne and satellite platforms.

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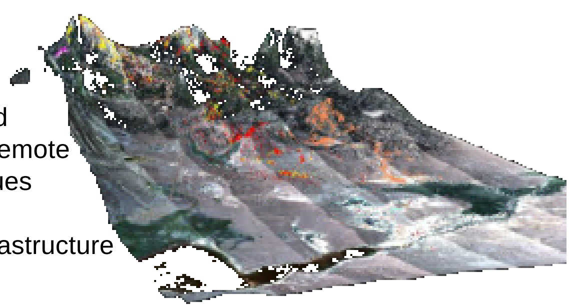
Lawrence Livermore National Laboratory



- **Title**:
  Hyperspectral and Radar Imaging Remote Sensing Techniques for Natural Gas Transmission Infrastructure

- **Description**:
  Develop hyperspectral geobotanical and radar imaging remote sensing techniques for detecting and evaluating third party damage, detecting and discriminating leaks and monitoring pipeline system reliability.

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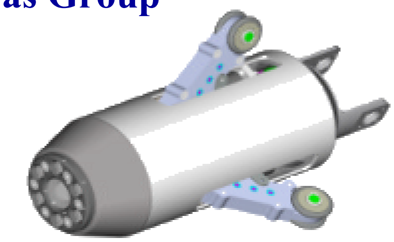
New York Gas Group



- **Title:**

  EXPLORER: A Long Range Untethered Live Gasline Inspection Robot System

- **Description:**
  - A long-range untethered visual inspection robot prototype for use in distribution pipelines 6 to 8 inches in diameter, capable of independent movement and communication of 5,000 - 10,000 ft.
- **Partners:**
  - Carnegie Mellon University, Keyspan, Central Hudson Gas and Electric, Consolidated Edison of New York, Niagara Mohawk Power Corporation, New York State Electric and Gas, Orange and Rockland Utilities, Rochester Gas and Electric, NASA

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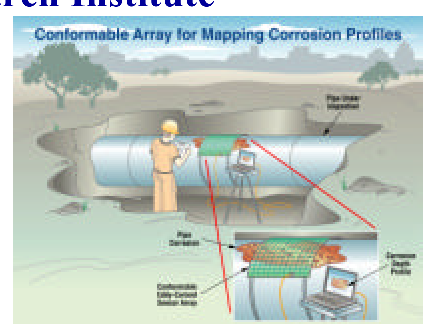
Southwest Research Institute



- **Title:**
  - Conformable Array for Mapping Corrosion Profiles
- **Description:**
  - A simple, rugged, low cost device that that can be used to quickly map the corroded surface of a pipe, without cleaning of the pipe surface. The device will use eddy current sensing coils in a conformable array that can be wrapped around the pipe surface.
- **Partners:**
  - Clock Spring Company, L.P. (TX)

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Pig Technologies

- Electromagnetic and Acoustic Technology (EMAT)
- Non-Linear Harmonics
- Circumferential Magnetic Flux Leakage (MFL)

•Tuboscope Pipeline Services
•Southwest Research Institute
•Battelle

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Southwest Research Institute

- **Title:**
  - Monitoring Technology for Early Detection of Internal Corrosion for Pipeline Integrity
- **Description:**
  - A new inspection technique for unpiggable pipelines based on Magnetostrictive (MsS) torsional guided wave technology.
- **Patners:**
  - Clock Spring Company, L.P. (TX)

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New York Gas Group

- **Title:**
  - Test Kit for In-Situ Measurement of PCBs in Pipelines
- **Description:**
  - An advanced, accurate, user friendly, rugged, rapid, field portable test kit for the in-situ measurement of Polychlorinated Biphenyls (PCBs) in natural gas pipelines.
- **Partners:**
  - Advantica Technologies Inc.

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Albany Research Center

- **Title**:
  - Electrochemical Noise Sensors for Detection of Localized and General Corrosion of Natural Gas Transmission Pipelines
- **Description**:
  - The work will develop and test a novel electrochemical noise (EN) sensor to measure corrosion in natural gas pipelines. The developed sensor will couple with linear polarization resistance (LPR) and harmonic distortion analysis (HAD).

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Oak Ridge National Laboratory

- **Title:**
  - New Acoustic Wave Pipe Inspection System
- **Description:**
  - This project will develop and demonstrate a new waveguide pipe flaw detection technique that has the potential to detect pipeline flaws in a single pass at speeds of approximately 2 miles per hour.

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Pacific Northwest National Laboratory

- **Title:**
  - Ultrasonic Measurements of Plastic Strain in Pipelines
- **Description:**
  - PNNL will develop and demonstrate a novel ultrasonic nondestructive test method to detect and evaluate the severity of third party damage in pipelines.
- **Partners:**
  - Battelle Memorial Institute Pipeline Inspection Facility
  - National Institute of Standards
  - Pacific Gas and Electric

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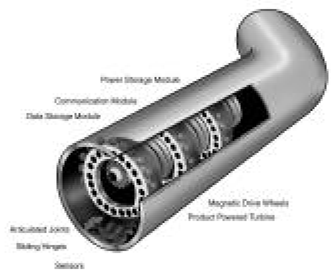
Sandia National Laboratory

- **Title:**
  - Sensor Development for the IPP Robotic Vehicle for Internal Detection of Gas Pipeline Defects



- **Description:**
  - SNL will evaluate the application of emerging sensor technology that will be compatible with their IPP robotic vehicle. The robotic system will be capable of nondestructively locating and assessing the severity of pipeline defects such as corrosion, stress corrosion cracks and dents

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Gas Technology Institute

- **Title:**
  - Differential Soil Impedance Obstacle Detection
- **Description:**
  - A unique down-hole obstacle detection sensor for Horizontal Directional Drilling (HDD) equipment. This sensor utilizes a differential soil impedance measurement technique that will be sensitive to the presence of plastic, ceramic, and metallic obstacles in the proximity of the HDD head.

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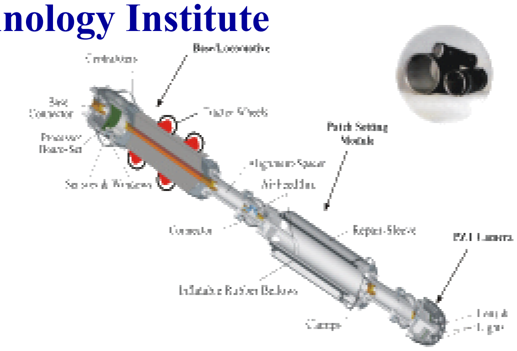
- **Title:**
  - Sealing Large Diameter Cast Iron Pipe Joints under Live Conditions



- **Description:**
  - A robotic system capable of sealing multiple cast iron bell and spigot joints from a single pipe entry point. This system will effect repairs while the pipe remains in service.

- **Partners:**
  - Maurer Technology Inc.

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- **Title:**
  - Development of an Environmentally Benign Microbial Inhibitor to Control Internal Pipeline Corrosion

- **Description:**
  - The work proposes to use natural chemical compounds isolated from plants to prevent, mitigate and/or eradicate corrosion due to microbial activity inside of metal (iron and stainless steel) natural gas transmission pipelines. Initially proposed natural products consist of oils extracted from the seeds and pods of pepper plants. Prior work suggests that these oils may prevent microbially influenced corrosion.

NETL

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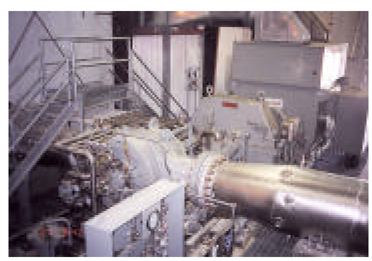
Idaho National Engineering and Environmental Laboratory

- **Title**:
  "Smart Pipe"
  Integral Communication, Damage Detection and Multiple Sensor Application in Pipelines
- **Description**:
  Thermally sprayed conductive traces applied in natural gas transmission and distribution pipelines that can be used for pipeline communications, detection and location of damage and as a conductive pathway for attaching or embedding sensors for performance monitoring.

NETL

Strategic Center for Natural Gas

Southwest Research Institute

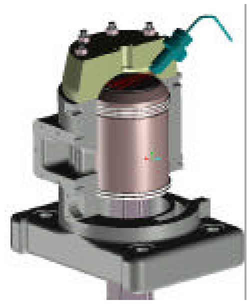


- **Title:**
  - Turbo-Compressor Direct Surge Control
- **Description:**
  - Increased operational flexibility of natural gas transmission turbo-compressors through Direct Surge Control. Using an Incipient Surge Detector (ICD) and an active control system the compressor may operated much closer to the surge limit.
- **Partners:**
  - Siemens Energy & Automation, Inc. (SEA)
  - Gas Machinery Research Council (GMRC)

NETL

Strategic Center for Natural Gas

Colorado State University
Engines and Energy Conversion Laboratory



- **Title**:
  Retrofit Micro-Pilot
  Ignition System

- **Description**:
  Improvement to Pipeline compressor reliability through retrofit Micro-Pilot Ignition System. This system will increase operational integrity, increase fuel efficiency, and reduce environmental impact of two-stroke natural gas compressor engines.

- **Partners:**
  Woodward Governor Company

Strategic Center for Natural Gas

Automatika, Inc.

- **Title:**
  - GASNET: Gasline Sensor Network System

- **Description:**
  - This project will develop a wireless network of small pipeline sensors that operators can use to monitor the real-time operations of active gas distribution mains, the smaller pipes that deliver gas to residences and businesses.

- **Partners:**
  - New York Gas Group and its associated utilities

Strategic Center for Natural Gas

Kansas State University

- **Title:**
  - Virtual Pipeline System Testbed to Optimize the U.S. Natural Gas Transmission Pipeline
- **Description:**
  - KSU will develop a computer model that will allow operators to identify the most reliable and lowest cost path to deliver natural gas to the consumer by integrating both the operation of compressor stations and different pressures, flow rates and other variables in the pipeline.

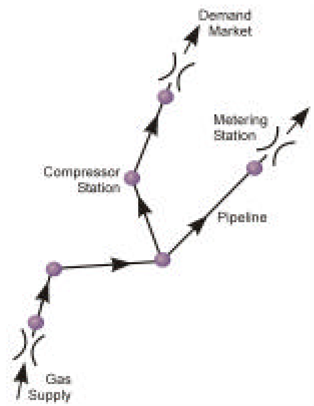


Illustration of a pipeline

Strategic Center for Natural Gas

Louisiana State University

- **Title:**
  - Dynamic Modeling and Automatic Feedback Control of Natural Gas Pipeline Networks
- **Description:**
  - LSU will replace many of the manual operations in managing the flow of natural gas through pipelines and compressors with cutting-edge automated systems. The university will develop modeling tools and automated feedback controls for large-scale pipeline networks.

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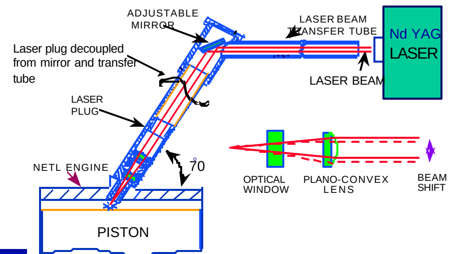
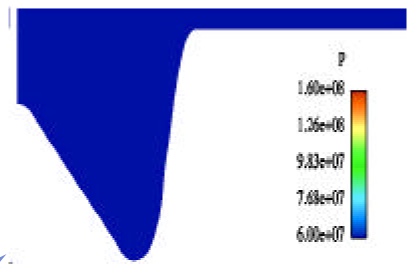
NETL In-House Reciprocating
Engine/Compressor Activities

- •Develop engine knock mitigation tools, models and strategies to improve compressor engine efficiency and emission performance
- •Develop highly durable spark ignition system based on non-intrusive laser technology





- •Engine power output may be greatly increased at higher BMEP. This requires attention to engine knock margin. (Alleviates additional engine installation and permitting needs)
- •Laser ignition may aid in both active and passive knock control while providing a more durable spark source.

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Future Plans

- Broad Based Financial Assistance Solicitation
- SBIR
- Targeted Solicitation (March 2003)
- National Lab Call
- University Consortium

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Section **3.0**

WORK-GROUP PRODUCTS

Following the plenary session, the participants worked in three breakout groups. Their placement was based on their areas of expertise. The three groups working in parallel worked to provide the following:

- Key barriers and issues to infrastructure reliability,
- R&D opportunities to overcome these issues,
- Gaps in the current portfolio of projects, and
- Implementation strategies to attain the goals and address the gaps.

The detailed results are presented as follows:

A. Infrastructure Security and Energy Assurance Group
B. R&D Innovations Group
C Interdependencies, Modeling, and Integration Group

A. SECURITY AND ENERGY ASSURANCE GROUP

Participants:
Security and Energy Assurance Group

NAME	ORGANIZATION
Rodney Anderson	DOE/NETL
Jeffrey Barger	Dominion Transmission, Inc.
Richard Benson	Los Alamos National Laboratory
Lawrence Borski	Williams Gas Pipeline
Armando Carmona	City Public Service of San Antonio
Sam Clowney	El Paso Corp.
Daphne D'Zurko	New York Gas Group
Steven Gauthier	Gas Technology Institute
Julianne Kiara	DOE/NETL
R. Earl Lewis	BGE
Robert O'Connor	Equitable Resources
Mark Ringwelski*	Enron Transmission Services
Geoff Rogers	Duke Energy
Hagen Schempf	Carnegie Mellon University
Ray Ward	Memphis Light, Gas, and Water
Cynthia Wilson	WV Public Service Commission

*** Report Out Presenter**

FACILITATOR: JACK EISENHAUER, ENERGETICS, INCORPORATED

The integrity and reliability of the natural gas delivery infrastructure is critical for all aspects of the U.S. economy. Over the past decade, the natural gas industry has actively pursued new technologies and practices that improve infrastructure reliability as aging assets require upgrading and increasing gas demand requires new construction. However, the attacks of September 11 have added a new dimension to reliability: securing the infrastructure against intentional and malicious attacks.

Infrastructure security and energy assurance encompasses a broad range of issues. It includes assessing threats and vulnerabilities, detecting and preventing intrusion, evaluating and mitigating damage, and responding to emergencies. It includes protection against deliberate attacks on the system as well as unintentional intrusions and natural disasters. Potential solutions will require the development and implementation of advanced technologies, but also coordination of information and resources among the gas industry, state and federal agencies, and interdependent networks.

The task of protecting the vast network of natural gas pipelines, compressors, and related utilities is enormous. In the near term, the industry is limited in what it can do to prevent physical attacks because its assets are extensive and dispersed throughout the country. However, much can be done to prevent cyber attacks, detect physical intrusions, and respond more effectively to problems as they arise. Many of the technologies and practices to improve security and energy assurance exist today, although not necessarily within the natural gas industry. Other technologies may be years away from actual operation but promise exceptional capabilities to prevent both physical and cyber attacks. However, the financial and technical resources required to address security challenges are coming at a time when the energy industry is continuing to change in response to restructured markets. As a result, the responsibilities for protecting, maintaining, constructing, and modernizing the natural gas infrastructure are not always clearly defined.

Achieving full energy assurance of the natural gas delivery infrastructure is difficult due to a variety of technical and institutional barriers. Any effort to make the natural gas network more secure must recognize that there are millions of miles of pipelines representing billions of dollars of physical assets installed over the past century. Nearly all of the infrastructure is privately owned and was intended for use in regulated energy markets and with little consideration of malicious attacks. Preparing these systems for the reality of deregulated markets and potential terrorism will take significant time and financial investment.

The key aspects of infrastructure security and energy assurance fall within the six areas outlined below.

- ***The current configuration of the natural gas infrastructure is difficult to protect against physical attacks***. The network of pipes, compressor stations, valves, controls, and related utilities is **large, diffuse, and remote**. While much of the infrastructure is naturally protected because it is located underground, there are plenty of **exposed above-ground pipes** that are unprotected. **Compressor stations are often remote and hard to access**, making it difficult to respond quickly to problems.

- ***Automated control systems are vulnerable to cyber attack.*** The automated systems that control pipeline and compressor operations (SCADA systems) do not operate securely. There is **no hardened, secure communication technology** used by the industry that would prevent cyber intrusion. Furthermore, there is **no industry standard for secure information and communication protocols**, making it difficult for the industry to proceed with a common approach for secure SCADA systems. The protocol for one equipment manufacturer may differ from its competitors.

- ***Potential threats and vulnerabilities of the natural gas infrastructure are not well understood.*** The industry does not have a good grasp of the critical nodes and vulnerabilities of the natural gas delivery system because there have been **few threat and vulnerability assessments** performed, particularly at a regional and national level. In addition, it is not clear what **security and classification of information** is appropriate for this information.

- ***The industry has limited ability to detect intrusion and damage from outside forces.*** There are few technologies available to **warn of third-party intrusion**, whether it is unintentional (digging near a line) or unintentional (planned terrorism). When intrusion does occur, there is no **real-time damage detection** that alerts controllers of the event, its location, and severity. Moreover, the **lack of an active system to prevent intrusion**, means that companies can only respond once damage is done.

- ***The industry has limited tools to evaluate, inspect, and respond to pipeline problems.*** **Tools for inspecting the interior and exterior of pipelines are inadequate** to determine potential problems spots or to determine the extent of damage. In addition, there are **no robust tools for evaluating pipeline integrity**. When damage occurs and repair is needed, companies are **unable to excavate quickly without damaging underground utilities**. Companies may also have **difficulty moving gas to areas of greatest need** during a major emergency.

- ***New security requirements have created new responsibilities for funding secure technologies, sharing information, educating the public, and working with law***

enforcement organizations. Competitive energy market conditions have **constrained financial and manpower resources** for responding to security needs. It is unclear, for example, **who is liable for terrorist-induced damage**. Security needs have created a **new level of complexity for sharing and controlling information**, both among companies and with government agencies. **New relationships must be created with law enforcement** and other organizations involved in energy assurance. **Educating the public** regarding emergencies and damage control must also be added to the security responsibilities of pipeline companies and utilities.

Table 1-1 presents the detailed results for barriers, Table 1-2 the opportunities, and Table 1-3 the implementation plans.

Security and Energy Assurance

TABLE 1-1. BARRIERS

◆ = VOTE FOR PRIORITY TOPIC

PHYSICAL PLANT: MONITORING & LIMITATIONS	DETECTION: UNDERGROUND FACILITIES & LEAKS	OUTSIDE FORCE DAMAGE (INCLUDING THIRD-PARTY)	DATA ACQUISITION & INFORMATION TECHNOLOGY	SYSTEM MONITORING, ANALYSIS & CONTROL	REGULATORY & INSTITUTIONAL	CONSTRUCTION, MAINTENANCE & REPAIR	SECURING THE INFRASTRUCTURE	
• Material limits on transmission and distribution • Monitoring of physical plant condition • Inadequate tools to evaluate pipeline integrity ◆◆ • Lack of predictive pipe–failure models • Need better pipeline inspection tools–internal and external ◆◆◆◆ ✳ Get back to operating at design capacity ◆	• Lack of technician to locate and identify facilities • Rapid leak detection needed–remove, non-intrusive • Ability to locate non-metallic pipe	• Warning of third-party intrusion ◆◆◆◆◆◆ ◆◆◆◆ • Real-time damage detection ◆◆◆	• Converting data, real-time tools • Lack of sensors for dynamic applications • Lack of automated information/data management ✳ Ability to handle complex information during emergency	• Lack of understanding of transient flow and impacts • Lack of real-time consumption information • Systems to respond to, variable delivery cycles • Improving overall efficiency of pipeline and compressors ◆◆◆	• Limitations on operating pressures • Common basis for technical evaluation and certification • Permitting process • Limited dollars for technical improve-ment ◆◆ ✳ Environ-mental concerns ◆◆	• Better guided boring technologies • Ability to excavate quickly without damage to underground utilities ◆◆◆◆ • Need low-cost pipeline rehab/retrofit technology ◆ • Lack of intelligent, trenchless technology	✳ Threat and vulnerability assessments needed ◆◆◆◆◆ ✳ Security/ classification of information ◆ ✳ Lack of industry standards for secure information and protocol communication ◆◆◆◆◆◆ ✳ No hardened secure communication technologies ◆◆◆◆ ✳ New level of complexity, information sharing and control ◆ ✳ New organizational ties need to be established ✳ Large, diffuse infrastructure: remote ◆◆◆◆ ✳ Accessibility of facilities (compressor stations, need quick response ◆◆◆ ✳ Exposure of above ground pipes ◆◆◆◆ ✳ Moving gas to areas of greatest need after emergency ✳ Identify responsibilities and liability of problems ◆◆	✳ New funding question: Who pays? ◆◆◆ • Response to security needs with financial and manpower constraints ◆◆◆ ✳ Different assurance objectives at work ✳ Need for fuel flexibility at end-use for more robust system ◆ ✳ Operational efficiencies among infrastructure (H_2O, electric, etc.) ✳ Balancing need to investigate versus getting back on line ✳ Educating the public ◆◆◆ ✳ instructions ✳ emergency resource ✳ damage control ✳ Need an active system to respond/prevent ◆◆ ✳ Emergency responder training and protocol ✳ Controlling internal threats (within companies) ✳ Voluntary versus required mutual assistance

● = Topics identified in earlier roadmapping
✳ = New topics

Security and Energy Assurance
Table 1-2. Opportunities
◆ = Vote for Priority Topic

Third Party Damage	Compressors	Materials	Education & Training	Funding Issues	Pipeline Efficiency
• Right-of-way monitoring ◆◆◆◆◆◆◆◆◆◆◆ – Satellite imaging ◆ – Real-time detection • Warning 3rd party intrusion equipment and software needed, user-friendly GPS • Soft dig excavator ◆◆◆ • Minimize 3rd party damage with improved GPS data • Rehab technology to reduce likelihood of failure from 3rd party damage ◆◆	• Retrofit technology to widen operational range of computer equipment • Retrofit technology to reduce fuel cost ◆ • Retrofit technology to uprate existing horsepower ◆ • Retrofit technology to meet more stringent environmental requirements ◆◆	• Plastics technology, self-healing ◆ • Retrofit ballistic armor pipe covering for above-ground piping protection ◆	• Internet-based network for online training • Educational tools, methods and training for dissemination to the public	• Joint industry-regulatory work group to explore funding issues ◆ • Funding—possible clearing house of any government funds available	• Cost-effective methods improving efficiency
Security	**Underground Detection**	**Boring**	**Inspection**	**Automation**	**Repair**
• Infrastructure location classification system ◆◆◆ • Pipeline "force-field" with tie-ins for crews ◆◆◆ • Perimeter (fence), motion detection (economic) ◆◆◆ • Develop low-cost application other end-use controls that operate under broader range of gas supply characteristics • Conduct vulnerability assessment for natural gas system ◆◆◆◆ – Educate the industry on VA results – Industry-government working group for VA standards – VA software and evaluation tools • Autonomous isolated facility stand-alone security system ◆◆ • National emergency warning system ◆◆◆◆◆◆◆ • Sharing of imagery, DOD satellites • Standard communication method that flows from governmental agencies to field • Secure SCADA systems ◆◆◆◆◆ – Standards for secure communication – Hardware and software encryption (transfer) – Test facility to confirm (cross-manufacturer communication capability	• Acoustic device for leak detection and 3rd party hits ◆◆◆	• Boring equipment with real-time damage detection ◆◆◆◆◆	• Inspection tools for non-piggable mains ◆◆◆◆◆ – Self-propelled internal inspection tool	• Develop industry standards (non-proprietary) for controls and communication equipment ◆◆◆	• Develop construction excavation equipment for low cost street trenching, moves fast, minimizes mess ◆ • Rapid micro/keyhole excavation tools for external corrosion DA validation

Security and Energy Assurance
Table 1-3. Implementation Plans

	Characteristics & Requirements	R&D Elements	Critical Steps	Collaborations	Schedule & Money
Right-of Way Monitoring/Third Party Damage Prevention	• Third-party damage control mechanisms • Accurate GIS map with automatic (instant) update • Reliable, no false positives • Devices that alert people from unintentional intrusion • Real-time information • Discern normal activity versus abnormal activity • One-call system with monitoring activation	• Early warning of intrusion to company/"outsider" • Communication mechanisms, secure • Intrusion prevention devices ("turn off" a backhoe), device that feeds to GPS • Use fiber optics to integrate with detection system • Sensing devices that discriminate – acoustic – satellite imaging – invisible • "Fields" around buried pipes, radio signals around metal pipe – retrofit for existing pipe – new construction – tracer wires for plastic pipes	• Solid GPS/GIS system • Sound business case • Integrate with partners; spread risk/cost/ responsibility – ideal but hard to obtain • Easy, quick and cheap to implement (sensors, comm, er), use existing facilities	• Common ground alliance • Pipeline companies • LDCs • Regulators • OEM/manufacturer/ suppliers • One call organization • Researchers • Federal government research money • Satellites	• Form/use alliances with other infrastructure • Identify most critical element – common ground alliance • Five- to ten-year time frame
Secure SCADA Systems	• Impervious to outside attack, no hackers • Perform current functions with no degradation • Applicable to existing hardware • Self-checking system, smart • Standardize nationwide → control and communication	• Agree upon industry consensus standard • Easily, automatic, low-cost updating of software • Testing and certification facility for ensuring interoperability of manufacturing equipment • Encryption algorithms and software development • Expert analysis of secure system • More sophisticated cyber monitoring and screening – wireless systems are not secure – hacker test facility	• Security vulnerability assessment • Agree on common standard • Examine how to leverage off of existing technologies • Resolving national and private interests	• SCADA and process control equipment vendors • Software engineers, various fields • Security experts (government, contractors, etc.) • Common ground alliance/other infrastructures • National issues—DOE, industry trade organizations • Federal government industry cooperation needed with money	

Security and Energy Assurance

TABLE 1-3. IMPLEMENTATION PLANS *(CON'T)*

	CHARACTERISTICS & REQUIREMENTS	R&D ELEMENTS	CRITICAL STEPS	COLLABORATIONS	SCHEDULE & MONEY
GOVERNMENT ROLE	• Government facilitated demonstrations – industry state-of-the-art – crossover and transfer from other industries • Government test bed facility • Showcase technology • Test new devices • Physical security of critical facilities – compressors – above-ground facilities (valves) – storage – meters – above-line valves				

B. R&D INNOVATIONS GROUP

Introduction

The R&D Group consisted of both technical experts and visionary leaders, resulting in a unique set of products. Although emphasis was occasionally placed on a far-reaching topic, the reality of the needs for near-term solutions for current problems dominated the session. Participants mentioned regulatory and institutional concerns as well as needs for funding, but this fell outside of the group's scope since R&D could improve these areas.

Participants: R&D Innovations Group

NAME	ORGANIZATION
Bob Bass	Southwest Research Institute
Dan Driscoll	DOE/NETL
Paul Gustilo	American Gas Association
Dave Johnson	Enron Corp.
Ibrahim Konuk	Geological Survey of Canada
Shreekant Malvadkar	DOE/NETL
Graham Midgley	Heath Consultants Incorporated
Bob Moody	CMS Energy
Randy Moss	Southern Cross Corp.
Bruce Nestleroth	Battelle
Jerry Paulus	City of MESA Gas
George Ragula	Public Service Electric and Gas Co.
Christina Sames	DOT/Office of Pipeline Safety
Crystal Sharp	DOE/NETL
Wes Soyster	Equitable Gas
Andy Theodos	Columbia Gas Transmission
*Bob Torbin	Foster-Miller, Inc.

*** Report Out Presenter**

FACILITATOR: ALICIA DALTON, ENERGETICS, INCORPORATED

What Are the Technology Issues and Barriers?

From previous work, a preliminary set of barriers was presented. The group updated the board to indicate new barriers that have developed. Some unique voting trends began to stand out – both new barriers and previously discussed issues were viewed as high priority. The highest vote-getter was a new barrier – integrity assessment of non-piggable transmission mains. The second highest priority, a need for better pipeline inspection tools both internal and external, fell into the same category of Physical Plant: Monitoring and Limitations. There was a tie for the third highest vote-getters. Real time detection and assessment of adversarial intruders to gate settings/meters at first barriers was listed under the new category of Security issues while the other high priority barrier, rapid leak detection needed that is remote and non-intrusive, belonged to the existing category of Detection: Underground Facilities and Leaks.

Nearly identical numbers of old issues were listed beside the new barriers. One new category was added, Security, but in general the group tried to stay focused on research and development since another parallel session was being held to address safety issues. Although highest priority barriers were identified, the voting was scattered, with many cards receiving just a few votes. This could have resulted from voting with respect to one's personal views only or because the problems surrounding infrastructure reliability are so widespread that there are no definite areas that everyone agrees are the most problematic. The complete barriers product can be found in Table 2-1.

What Are the R&D Opportunities to Meet the Needs?

The group brainstormed and analyzed R&D opportunities to respond to the requirements and barriers to infrastructure reliability. Most opportunities fit into the categories of the current portfolio of infrastructure reliability projects. No opportunities were indicated as Boring, and several new categories were added including Installation, Regulatory and Institutional, Utilization, and Security. The highest vote-getter belonged to the Inspection heading, advanced robotic technology for non-piggable mains (transmission). The second highest vote-getter was the sole opportunity in the Repair category – robotic repair of internal corrosion. The next highest priority opportunities were located in the Security, the Leak Detection, and the Regulatory and Institutional categories. An equal number of votes were given to development of a suite of cost-effective surveillance techniques, development of laser technology to leak survey lines above ground, and combination of government and industrial R&D efforts and management. The complete opportunities results can be found in Table 2-2.

Portfolio Gap Analysis

A structured gap analysis of the current portfolio of projects was completed based on the results of the opportunity voting and can be found in Table 2-3. Voting indicated that the overall highest priority gap was part of the Leak Detection category – development of laser technology to leak survey lines above ground. This gap was followed by a five-way tie for second place including the following: develop of magnetic flux leakage tools for better pit geometry, combine of government and industrial R&D efforts and management, advanced robotic technology for non-piggable mains (transmission), robotic repair of internal corrosion, and synergies compressor technologies, deliverability, reliability, efficiency, and emissions. From these top priority gaps, detailed implementation strategies would be developed. Due to time constraints the group could only complete four strategies, but it should be noted that the other two high priority gaps are still of great significance.

The participants felt strongly about 3rd party damage, which may not be apparent from the results. Many submissions from the group were crosscutting and related to 3rd Party Damage. A variety of ideas under Security, Leak Detection, Inspection, Repair, and 3rd Party Damage were all related. The group noted again that there was another session tasked to handle security and energy assurance.

Implementation Strategies

The first implementation strategy completed was for the development of laser technology to leak survey lines above ground. Requirements indicated for this opportunity included the following: repeatable, reliable, accurate results; aerial and hand-held versions; provide real-time data to remote source; and increase productivity. R&D specifications included weight under five pounds, range greater than 300 feet, and temperature range of operation from –40°F to 120°F. Some critical items noted included self-calibration, and portable and mobile capability. This opportunity could be lead by R&D organizations experienced in laser applications or by national laboratories. Industry would be involved for field tests, technical direction, and priority/ reevaluation while it would be necessary to keep states and the Department of Transportation involved and aware of the work being accomplished. R&D would take roughly two or three years and $9 million.

The second implementation strategy completed focused on the combination of government and industrial R&D efforts and management. Through a discussion regarding specific details, it became apparent that many attempts have been made in this area, but no one method meets everyone's needs. Further, finding just cause for each involved group may prove to be a stumbling block. This collaboration would have to reduce cost, meet frequently, share in funding of priority R&D, and bring the same people together each time. Two types of groups would be formed – a research advisory group, and various project advisory groups segregated by research category that would report to the research advisory group. It is critical to inform everyone of work by establishing a common one-page summary for projects. Group member selection should be accomplished by existing organizations and determination is needed regarding level of involvement and control given to co-funders.

Advanced robotic technology for non-piggable mains (transmission) was the basis for the third implementation strategy. Requirements for this technology included the following: no interference with operations, provide digital data, and can be left in the pipeline long-term. Specifications included self-powered, able to pass through four-inch pipes, and able to clear odd-shaped valve openings. Critical items included cost effectiveness, able to gain regulatory acceptance, and have optical capability. Industry would lead this work with collaboration from vendors and R&D organizations with robotic and pipe inspection expertise. This work could take three to five years and a total of $7-10 million.

A final implementation strategy detailed synergies-compressor technologies, deliverability, reliability, efficiency, and emissions. This would require new novel techniques, using waste heat to cool the intercoolers, and meeting anticipated environmental requirements. R&D products and specifications include increase valve and blade life, use less fuel than existing equipment, and improved security. Intellectual property issues and securing initial investment were part of the critical item list. End-users would lead this opportunity by collaborating with compressor manufacturers and instrumentation control manufacturers over a three to ten year time frame and funding varying from $1-100 million. All four of the complete implementation strategies can be found in their entirety in Table 2-4.

R&D Group

Table 2-1. What Are the Technology Issues and Barriers?

Physical Plant: Monitoring and Limitations	Detection: Underground Facilities and Leaks	System Monitoring, Analysis, and Control	Outside Force Damage (including 3rd party)	Data Acquisition and Information Technology	Regulatory and Institutional		Construction, Maintenance, and Repair	✳ Security
• Material limits on transmission and distribution • Monitoring of physical plant condition • Inadequate tools to evaluate pipeline integrity ◆ ✳ Only 30% of all pipeline are able to be inspected • Need better pipeline inspection tools – internal and external ◆◆◆◆◆ • Lack of predictive pipe-failure models ✳ Need for improved compression technologies ◆◆ ✳ No long-term view from purchasing decision makers ◆ ✳ Integrity assessment of non-piggable transmission mains ◆◆◆◆◆◆ ✳ Current accurate map information ◆◆◆ ✳ Lack of large diameter/high pressure CCTV inspection "Live" ◆ ✳ Lack of non-destructive testing for PE joints ✳ Redefine pigging practice ◆◆	• Lack of technology to locate and identify facilities • Rapid leak detection needed-remote, non-intrusive ◆◆◆◆ • Ability to locate non-metallic pipe ◆◆◆ ✳ Lack of cast iron pipe joint locators ◆	• Lack of understanding of transient flow and impacts • Lack of real time consumption information ◆ • Systems to respond to variable delivery cycles ✳ Need more system optimization R&D ◆	• Warning of 3rd party intrusion ◆◆ ✳ Intentional ✳ Accidental • Real-time damage detection ◆	• Converting data → real-time tools ◆ • Lack of sensors for dynamic applications • Lack of automated information data management ✳ Advanced interpretations of close-interval survey data ◆◆ ✳ Data fusion ◆◆ – Format – Hardware – Software	• Limitations on operating pressures ◆ • Common basis for technology evaluation and certification • Permitting process • Limited dollars for technology improvements ◆ ✳ Clean Air Act impact on HP (new and existing compressor stations) ◆◆ ✳ Technology adoption inhibited by combination of regulatory and technology transfer issues ✳ Localized focus vs. industry focus ✳ Decrease in qualified personnel (technical)	✳ Lack of long term funding/vision/ commitment ◆◆◆ ✳ R&D and new materials should be exempt from regulatory restrictions ✳ Lack of cooperation, communication and data sharing among pipelines, LDCs, electric, etc. ◆◆ ✳ Personnel change – never work with same people twice ✳ Typically have non-technical people writing technical mandates ✳ Lack of idea forums to fully develop ideas ◆	• Need low-cost pipeline rehab/retrofit technology • Better guided boring technologies • Ability to excavate quickly without damage to underground utilities • Lack of intelligent trenchless technology ◆ ✳ Need for recon/ surveillance technologies ◆	✳ Rapid recovery plans for key facilities ◆◆ ✳ Real time detection and assessment of adversarial intruders to gate settings/ meters at first barriers ◆◆◆◆ ✳ Real time detection and assessment of intruders to compressor stations at first barriers ◆◆◆

● = Topics identified in earlier roadmapping
✳ = New topics

R&D Group

TABLE 2-2. What Are the R&D OPPORTUNITIES TO MEET THE NEEDS?

◆ = VOTE FOR PRIORITY TOPIC

INSTALLATION	3RD PARTY DAMAGE	REGULATORY AND INSTITUTIONAL	UTILIZATION	INSPECTION	REPAIR	MODELING	SECURITY
• Develop sonic excavation tools using harmonics ◆ • Develop programs to enhance trenchless technologies ◆◆ • Construction methods and technology to minimize installation and/or repair	• Combine satellite right of way surveillance with fiber optic cable vibration ◆◆	• Better communication between industry sectors – joint action –gas, electric, transmission, distribution • Split research from development • Develop a standard for mapping ◆◆ • Utilize military technology (military contractors) for industrial/public benefit ◆ • Combine government and industrial R&D efforts/ management ◆◆◆◆ – Allow industry development of ideas and feedback during R&D activities (better communica-tions)	• Natural gas reformer development to reduce air pollution and efficiency ◆ • Add molecule to natural gas to make inert then remove to make flammable ◆ • Commercial, residential storage systems ◆◆	• Develop magnetic flux leakage (MFL) tools for better pit geometry ◆◆◆ • Smaller robotic distribution technologies move through pipelines report anomalies ◆◆ • Through transmission inspection: transmitter inside sensor outside ◆◆ • Sensors for inspection crawlers ◆◆ • Advanced robotic technology for non-piggable mains (transmission) ◆◆◆◆◆◆◆ • Fast response sensor technology ◆ • Inspection pig detecting changes (dents, corrosion, coating)	• Robotic repair of internal corrosion ◆◆◆◆◆	• Develop advanced algorithms to maximize information from existing inspection data ◆ • Infrastructure optimization to improve reliability. Examine all pipelines. Connect logical pipelines via headers ◆ – North to South – East and West	• Develop suite of cost-effective surveillance techniques ◆◆◆◆ – Develop satellite images for continuous patrol/survey • Develop standards for security assessments and methods • Put up a force field ◆◆ • Develop DOD-type intelligence to help guide pipelines above ground

R&D Group

TABLE 2-2. WHAT ARE THE R&D OPPORTUNITIES TO MEET THE NEEDS? *(CON'T)*

◆ = VOTE FOR PRIORITY TOPIC

AUTOMATION	MATERIALS	COMPRESSORS	LEAK DETECTION	UNDERGROUND DETECTION
• High speed wireless communication technology ◆ • System optimization – Models – Sensors/controls • Sensor/instrument ◆ – Gas quality – Meters – NDE/TVDT – Security – Pipes – Machines	• Coating for PE pipe to reduce installation cost • Non-corroding high pressure piping materials • Materials R&D – New pipes – Reliability	• Synergies - compression technologies, deliverability, reliability, efficiency, emissions ◆◆ – Existing equipment – New novel techniques – Monitoring controls • New engine technologies countered opposed piston design ◆	• Develop laser technology to leak survey lines above ground ◆◆◆◆ • Visual leak detection using infrared imaging ◆◆◆	• Retrofit device to make PE pipe locatable with current technology ◆◆

R&D Group
Table 2-3. Portfolio Gap Analysis
◆ = Vote for Priority Topic

Partially in the Portfolio				
3RD Party Damage	**Installation**	**Security**	**Leak Detection**	**Inspection**
• Combine satellite right of way surveillance with fiber optic cable vibration ◆◆ – Satellite to assess what's being detected	• Develop programs to enhance trenchless technology ◆◆◆◆ – Elimination of all penetration	• Develop suite of cost effective surveillance techniques ◆◆ – Develop satellite images for continuous patrol/survey	• Develop laser technology to leak survey lines above ground ◆◆◆◆◆◆◆◆ • Visual leak detection using infrared imaging ◆◆	• Develop MFL (magnetic flux leakage) tools for better pit geometry ◆◆◆◆◆ • Smaller robotic technologies move through pipe and report anomalies – distribution ◆ • Sensors for inspection crawlers ◆

Not in the Portfolio						
Utilization	**Compressors**	**Repair**	**Underground Detection**	**Inspection**	**Regulatory and Institutional**	**Security**
• Commercial and residential storage systems ◆◆◆ – Downstream of meter – Increases service reliability – Peak shaving – Be able to control release (time of day) – time and pressure – Creates additional upstream capacity	• Synergies compressor technologies, deliverability, reliability, efficiency, emissions ◆◆◆◆◆ – Existing equipment – New novel technologies – Monitoring controls – Integrated engine/compressor controls – Use engine waste heat to create new species fuel to intake manifold – reduce emissions, increase efficiency, coil reformer $CH_4 + H_2O \rightarrow CO + 3H_2+$ (new species) – In-line compressors	• Robotic repair of internal corrosion ◆◆◆◆◆ – Robotic repair of external corrosion – Self healing pipe	• (Retrofit) device to make PE pipe locatable with current technology ◆	• Through transmission inspection: ◆◆ – Transmitter in pipe – Sensor outside • Advanced robotic technology for non-piggable mains (transmission) ◆◆◆◆◆ – Address varied causes of "non-piggable" lines	• Develop a standard for mapping ◆◆ • Combine government and industrial R&D efforts/ management ◆◆◆◆◆	• Put up a force field – Establish 3D perimeter

R&D Group

Table 2-4. Implementation Strategies

	Requirements	R&D Products Elements and Specifications	Critical Items and/or Steps (make or break)	Who Leads? Collaborations	Time/$
Develop Laser Technology to Leak Survey Lines Above Ground	• Repeatable, reliable, accurate results • Minimal maintenance requirements • Aerial and hand-held versions • Not more than 2 man operations • Based on other applications if possible • Easy calibration • Methane ethane specific • Has search mode and pinpoint mode • Provide real time data to remote source • Performance equal to/or better than current technology • Increase productivity • Easy, fast setup • Valid in windy conditions • Use by PL operations field staff • Available 24/7 • Equivalent sensitivity to existing equipment • East to use/minimal training	• Eye safe • Lightweight less than 5 pounds • All weather operation $^{-}40^{o}F<T<120^{o}F$ • Range >300' • Multi-sensitive <10 ppm to UEL • Explosion proof intrinsically safe • Weighs not more than 5 pounds • At least 8 hours operation on one charge • Field cal. by non-techs • Non-interfering with other instruments • Use at up to patrol aircraft speeds	• Self calibration • Review existing R&D and either support or drop projects depending on success potential • Keep end-users involved throughout process • Adaptable for hand held and aerial use • Determine minimum power requirements to evaluate safety vs. practicality • Portable and mobile capability	• Leaders – R&D organizations experienced in laser applications – National lab • Collaborators – Industry – Field tests, technical direction, priority/reevaluation – States and DOT need to be involved and aware	• R&D 2-3 years • $9M

R&D Group

Table 2-4. Implementation Strategies (con't)

	Requirements	R&D Products Elements and Specifications	Critical Items and/or Steps (make or break)	Who Leads? Collaborations	Time/$
Combine Government and Industrial R&D Efforts/Management	• Broad forums and focused groups • Bring together same people every time • Frequent meetings several times a year • Decrease environmental Impacts • Share in the funding of priority R&D • Decrease cost • Review schedule • Not Ad Hoc • Maximize benefit of limited resources • More efficient use of resources • Coordinate defining R&D top needs • Coordinate in the information distribution and tech transfer	• Form research advisory group • Form project advisory group that reports to the research group	• Inform everyone of work establish a common one page summary for projects	• Leaders – OPS, DOE, regions and states, municipals, industry-increase level • Research advisory (dozen or less) – AGA, APAGA, NGA, DOT, DOE, NARUC, PRCI – Individual utilities viewed as R&D industry leaders – Use organizations to select actual players – Co-funders to some extent • Multiple project advisory (segregated by category of research) – Techies – Use organizations to select actual players – Co-funders to some extent	• ?????
Advanced Robotic Technology for Non-Piggable Mains (Transmission)	• Not interfere with operations • Maneuver through all obstacles in pipeline • Easy to launch • Vehicle capable of multiple sensor technology • Accurate locating of defects • Does not miss significant anomalies • Meet DOT requirements for inspections • Competitive with other pigging technology • Repeatable reliable and accurate results • Detect corrosion and/or evaluate dents and gouges • Provide digital data • Can be left in pipeline – long term • Compatible with current pigging technologies	• Powered – Bi-directional • Self powered • Sensitive to critical defect sizes • Travel meters to miles • Use in live gas mains • Go through as small as 4-inch pipe • Real time results wireless communication • Good for up to several miles • Clear odd-shaped valve openings • Self-diagnostics	• Critical step – determine type of sensors • Operate in fluid filled lines • Cost-effective • Vehicle technology • Regulatory acceptance • Locate non-piggable lines for "real world" testing • Is the needed sensor technology available? • High reliability • Optical capability • Start with sensor or vehicle? • Develop specs for test pipeline – Valve types – Slopes – Moisture • Self propelled	• Lead – LDCs, industry, end-users • Collaborators – Vendors – R&D organizations with robotic and pipe inspection	• 3-5 years • $7-10M

R&D Group

TABLE 2-4. IMPLEMENTATION STRATEGIES *(CON'T)*

	REQUIREMENTS	R&D PRODUCTS, ELEMENTS AND SPECS	CRITICAL ITEMS AND/OR STEPS (MAKE OR BREAK)	WHO LEADS? COLLABORATIONS	TIME/$
SYNERGIES – COMPRESSOR TECHNOLOGIES, DELIVERABILITY, RELIABILITY, EFFICIENCY, EMISSIONS • **EXISTING EQUIPMENT** • **NEW NOVEL TECH.** • **MONITORING CONTROLS**	• Increase rangeability on existing equipment • Use waste heat to cool intercoolers (absorption) • Provide improvements – Efficiency – Emissions – Reliability – Deliverability • New novel techniques – Inline compression – Variable stake re-cops • Can operate over a wide range of flows • Fit within current physical envelope • High efficiency • Meet anticipated environmental requirements • Integrate engine/compression controls • Can operate over a wide range of pressures	• Smaller and portable • Reduce NO_x etc emissions • No cast metal • Increase valve of blade life • Use less fuel than existing equipment • Use engine waste heat to create new species fuel to intake manifold reduce emissions, increase efficiency – coil reformer $CH_4 + H_2O \rightarrow CO + 3H_2$ (new species) • Handle off-spec gas • Improved security	• Involve control and compressor manufacturers • Acceptance and field testing of novel designs • Market size/costs • Securing initial investment • Generating and approval of new industry standards • Intellectual property (patent) issues • Determine HP market priority, i.e., size of unit • Target market potential in horsepower	• Lead – End users • Collaborators – Compressor manufacturers – Instrumentation control manufacturers	• 3-10 years • $1-100M

C. INTERDEPENDENCIES, MODELING AND INTEGRATION GROUP

The group focus was on the growing national and regional interdependencies between elements of the natural gas infrastructure, as well as with other energy and related infrastructures (e.g., electricity, water, communications). The make-up of the group was particularly well suited to this focus, with even representation from pipeline and local distribution components of the infrastructure, as well as electricity generation and transmission.

Participants: Interdependencies Modeling and Integration Group

NAME	ORGANIZATION
John Bayko	Enbridge Consumers Gas
Terry Boss	INGAA
Bruce Campbell	Gas Technology Institute
Robert Cupina	Federal Energy Regulatory Commission
David Damon	Dominion Resources
Shari Dunn-Norman*	University of Missouri/Rolla
Gary L. Forman	Nisource
Christopher Freitas	DOE/FE
Tom Hancock	TVA
Rondle Harp	DOE/NETL
Walter Kasperczyk	National Fuel Gas Supply Corp.
Thomas Kraft	Wisconsin Electric/Wisconsin Gas
Tony Savino	KeySpan Energy
Nancy Shultz	Williams Gas Pipeline
Al Yost	DOE/NETL

*** Report Out Presenter**

FACILITATOR: JIM CAREY, ENERGETICS, INCORPORATED

Barriers

Given the workshop purpose of updating the natural gas infrastructure roadmap, the starting point for brainstorming was reviewing the set of major barriers identified in earlier workshops. The group then added a range of new items, from cyber and physical vulnerability to failure prediction of infrastructure components. Voting for high-priority topics showed emphasis on both already identified and new topics. Important topics previously identified include:

- Warning of third-party intrusion
- Real-time detection of damage
- Tools to evaluate pipeline integrity.

New topics included:

- Interdependencies between gas and electric systems
- Cyber and physical security
- Intelligent systems for monitoring physical plant assets
- Systems for the prediction and prevention of failure
- Improving system flexibility to respond to upsets and facilitate recovery.

The complete results are shown in Table 3-1.

R&D Opportunities

The barriers discussion started with the main R&D categories in the current program portfolio, as presented in the plenary session. As R&D topics were identified during brainstorming, they were placed either under a current category or a new category as appropriate, with DOE program representatives providing clarification of current portfolio efforts. Priority topics covered a mix of current and (potentially) new portfolio categories.

They include:

- Improved materials for high-pressure piping
- "Intelligent" systems for identification of and response to perturbations at multi-system, system, and component levels
- Wireless remote sensing devices for pipelines and excavating equipment
- In-the-pipe technologies for inspection and repair
- Modeling/forecasting systems to improve nationwide gas deliverability
- Low-cost, "plug and play" communications equipment
- Low-cost security sensors and systems for detection and monitoring.

The complete results are shown in Table 3-2.

Implementation Strategies

Based on the high-priority items, five topics were selected for implementation planning. They are:

- Intelligent systems at the level of "skin": this encompasses systems and components that can operate with the high-sensitivity, rapid- feedback detection/response/healing capabilities of biological systems. Key issues for R&D are assuring effective integration within individual systems (i.e., supporting a full range of capabilities throughout a given system) and developing standardized protocols to enable multi-system benefits.
- Low-cost, in-the-pipe technology: this is for "universal" systems, with multiple tools (e.g., for inspection, cleaning, joining, repairing) that are compatible with a common platform. Two key targets for R&D are developing systems to launch tools without major system modifications or service interruptions, and overcoming the current cost reality of most robotic systems.
- Improved materials for high-pressure lines: this includes 2,500 psi high-pressure main pipelines and 100 psi small plastic pipe and 500-600 psi piping for local distribution systems. While some materials with the desired performance characteristics are available now, the key issue to be resolved in R&D efforts is cost-effectiveness.
- Low-cost detection and monitoring systems: these are for security purposes, with initial application to the most critical nodes in the infrastructure. Key issues are costs due to the sheer number of facilities and the need for less expensive alternatives to "guns and guards" that can be applied over the long haul.

- Tools to forecast/integrate gas demand: this is to provide information to guide system development and integration in order to support national and regional requirements for assured gas deliverability. Key issues of concern are the diversity and independence (i.e., as economically driven operating units) of various systems and the increasing market demand by gas users with highly variable loads.

The complete results are shown in Table 3-3.

Interdependencies, Modeling and Integration
TABLE 3-1. WHAT ARE THE TECHNOLOGY ISSUES AND BARRIERS?
◆ = VOTE FOR PRIORITY TOPIC

● PHYSICAL PLANT: MONITORING AND LIMITATIONS	● OUTSIDE FORCE DAMAGE (INCLUDES 3RD PARTY)	● DATA ACQUISITION AND INFORMATION TECHNOLOGY	● REGULATORY AND INSTITUTIONAL	● CONSTRUCTION, MAINTENANCE, AND REPAIR
• Material limits on transmission and distribution • Monitoring of physical plant condition • Inadequate tools to evaluate pipeline integrity ◆◆ ✳ Intelligent system needed ◆◆◆◆ ✳ Tools to access operation and maintenance with risk factors ◆ ✳ Real-time vs. discrete continuous measurement ✳ Control system to deliver off-peak • Need better pipeline inspection tools – internal and external • Lack of predictive pipe-failure models	• Warning of 3rd party intrusion ◆◆◆◆◆◆ • Real-time damage detection ◆	• Converting data → real-time tools • Lack of sensors for dynamic applications • Lack of automated information data management	• Limitations on operating pressures • Common basis for tech. evaluation and certification • Permitting process • Limited dollars for tech. improvement ✳ Maintain competition with protection of infrastructure ◆ ✳ Who pays for redundant capacity ✳ Ability to adopt new technology ✳ Lack of continuity of service after event ◆◆◆	• Need low-cost pipeline rehab/retrofit technology ◆ • Better guided boring technologies • Ability to excavate quickly without damage to underground utilities • Lack of intelligent trenchless technology ✳ Tools to determine requirements for maintenance and new systems ✳ Repair or replace plastic pipe ◆◆ ✳ Landowner concerns → non-intrusive infrastructure ◆◆◆

✳LONG-TERM STRATEGIES AND CAPABILITIES	✳SECURITY AND VULNERABILITY	✳COLLABORATION INTERNAL AND EXTERNAL	● SYSTEM MONITORING, ANALYSIS AND CONTROL	● DETECTION: UNDERGROUND FACILITIES AND LEAKS
✳ Loss of long-term focus and capabilities ◆◆ ✳ Need training and dissemination of knowledge ◆◆ ✳ Deregulation and mergers lose capabilities and corporate R&D ◆ ✳ Quarter to quarter vs. long-term strategic approach ◆	✳ Cyber and physical vulnerability ◆◆◆ ✳ ✳Interdependencies: gas and electric systems ◆◆◆◆ ✳ ✳Need cost effective technology for security ◆ ✳ Vulnerability with transmission and distribution system interdependencies ✳ Laid off worker sabotage	✳ Develop and better alliances between industry and government ◆◆ ✳ Crossover technologies: pool efforts to get links ✳ Silo effect: compete and compliment ✳ Understand impacts and benefits of technology	• Lack of understanding of transient flow and impacts • Lack of real time consumption information • Systems to respond to variable delivery cycles ✳ Prediction of failure ◆◆◆◆◆◆ ✳ Flexibility of system tie to economics with models etc. ◆◆◆◆ ✳ Affordability of obtaining data	• Lack of technology to locate and identify facilities • Rapid leak detection needed – remote, non-intrusive • Ability to locate non-metallic pipe ✳ Inability to detect small volume leaks

● = Topics identified in earlier roadmapping
✳ = New topics

Interdependencies, Modeling and Integration

TABLE 3-2. WHAT ARE THE R&D OPPORTUNITIES TO MEET THE NEEDS?

◆ = VOTE FOR PRIORITY TOPIC

✳ SECURITY	✳ ALTERNATIVE STORAGE	✳ CONSTRUCTION TECHNIQUES	✳ INTELLIGENT SYSTEMS	✳ ENVIRONMENTAL IMPACTS	● 3RD PARTY DAMAGE
• Develop low cost motion detection, monitoring, sensors/systems ◆◆ • Develop security audit – probe – for company to test their protective systems • (NSF) IGERT analogy • Develop training system for simulated attack – Attack "kit" – "Cascade failures" • Set up a "fly trap" for would be attackers	• Transient surge designs	• Landowner buy in ◆ – Co-locate gas, electrical, water in utility carriers – Communicate benefits – Replace existing pipe with higher capacity lines – Improve construction techniques – Low profile/impact • Trenchless technology to enable installation of 36" pipe like fiber optic duct	• Take sensing to level of "skin" for intelligent pipelines → models? ◆◆◆◆ • Nationwide energy control systems to be an activated in an emergency ◆◆◆ – Monitor flows – Route around outage • Remote detection systems to passively report flaws, equipment, intruders, etc. ◆◆ • Develop systems for: – Corrosion monitoring – Leak detection – Pressure – Location • Develop long-term sensor/robotic detection and repair for distribution systems continuous • Intelligent system – 3rd party intrusion – Damage detection	• Construction – landowner needs – Compressor noise – Reduction of emissions	• Develop "smart" pipe wireless remote sensing devices for pipelines and excavating equipment ◆◆◆◆ • Detection and prevention of 3rd party damage ◆◆ • Cost effective methods to detect intrusion and provide security in remote locations

● = In existing portfolio
✳ = Not in or partially represented in existing portfolio

Interdependencies, Modeling and Integration

Table 3-2. What Are the R&D Opportunities to Meet the Needs? *(con't)*

◆ = Vote for Priority Topic

● Repair	● Materials	● Compressors	● Leak Detection	● Boring	● Automation	● Modeling	
• Lower the cost of the in-the pipe technologies using new designs ◆◆◆◆ – Launching equipment – Internal repair methods • Extending service life of existing infrastructure	• Develop protective/healing materials for exposed pipe • Expandable metals • Material science for HP lines ◆◆◆◆ • Materials ◆ – Small diameter – High pressure – Ease of installation – Corrosion resistant	• Flexible compressor design for quick start-up and load following ◆◆ • Second (next) generation compressors 2,500 PSI	• Develop remote methane monitoring and sensing equipment for use in excavations for personal safety ◆	• Obstacle detection for HDD that produces 3-D imaging for all underground structures ◆	• Develop low cost standard communication equipment ◆◆◆◆ – Plug & play sensors and activators • Develop redundant and separate controls and communication for lines • Develop handheld devices and software for field data capture to eliminate field paperwork • Develop communication system to share information on status of gas transmission/supply ◆ • Develop national clearing house for system capacity information • Model gas delivery systems and develop "alternate path" strategies (dynamic delivery system) • Improve redundancy in transmission of gas (dynamic modeling)	• Develop information exchange protocols ◆◆◆◆ • Forecasting system of generation and LDC dispatching ◆◆◆◆ • Continuity of service – Post event recovery ◆ – Self healing pipe – Redundant pipe – Protocol for supplementing deliveries: -- Who's gas? -- Who pays? -- Who decides? – Standardized categories and alerts/ responses • Define impacts of distributed generation on gas delivery ◆ • Forecasting system for gas system based on electric dispatch and LDC ◆	• Modeling to identify worst contingencies (gas) and how it would affect entire energy infrastructure ◆ • Failure prediction utilizing non-invasive tools and models • Tools to repair/replace ◆ – Decision tree – Cost/benefit • Real-time flow models that can activate operational adjustments to large swings in load ◆ • Define/model "impact weighted capacity" • Develop better sensor/models to continuously track and predict corrosion • Relation between corporate optimization and global optimization • Provide capture mechanism for pipeline failure data → model if possible? • Risk analysis: Economic vs. actual life cycle

● = In existing portfolio
✳ = Not in or partially represented in existing portfolio

Interdependences, Modeling and Integration
Table 3-3. IMPLEMENTATION STRATEGIES

TOPIC	REQUIREMENTS/ CHARACTERISTICS	R&D PRODUCTS ELEMENTS AND SPECS	CRITICAL ITEMS AND/OR STEPS	WHO LEADS? COLLABORATIONS	SCHEDULE AND DOLLARS
TAKE/DEVELOP INTELLIGENT SYSTEMS TO LEVEL OF "SKIN" ◆◆◆◆◆◆◆◆◆	• Continuing sensing along system/pipe • Standardization: "Plug & Play" • Data Acq/trans/use – All through system – Multiple end-point • Entirely new sensing targets, e.g., no current/ developing analogues • For application to: – Intrusion Detection – Damage – Degradation Assessment – Leak – Failure	• Components – Sensors – Algorithms – Actuators – Feedback systems – Data/information protocols	• No success without integration • Screen existing/ developmental efforts • Application – specific refinements for these applications • Worry first about – 3rd party: — on equipment — other ways to do it – Failure/leak – Predictive failure	• Intersection with ANSI 12.19 • Intersection with ASTM • State PUCs • FERC	• Near: sensors on equipment and implementation in active projects • Mid: inclusion into planned projects • Long: application on a system-wide basis
DEVELOP IMPROVED MATERIALS FOR HIGH-PRESSURE LINES ◆◆◆◆◆	• Retrofit existing systems • Integrate with smart pipe with a brain that talks to you	• 2500 PSI Thinner wall pipelines • Small diameter plastic 100 PSI • Non-corrosive 500-600 PSI for distribution systems – Easy install – Multi-fittings	• Impact on installation, e.g., joints • Cost of pipe equals of cost of materials; thinner matters • There are things-on-the ground now, but cost reality is critical	• Safety and regulatory issues both retrofit and new	
DEVELOP LOW-COST IN-THE-PIPE TECHNOLOGY NEW DESIGNS FOR LAUNCHING AND REPAIR ◆◆◆◆	• Smaller excavation • Standard configurations • Top-entry launch • Live gas operations • Flexibility for any tool 6-24" • Applications – Clamp repairs – Joining – Inspection – Cleaning	• Launch system with universal application • Cost-effective and easy to use	• Define market opportunity in gas systems to robotics industry	• Industry university capabilities in "robotics" • Industry crossovers, e.g., nuclear	

Interdependences, Modeling and Integration
Table 3-3. Implementation Strategies (con't)

Topic	Requirements/ Characteristics	R&D Products	Critical Items and/or Steps (make or break)	Who Leads? Collaborations	Schedule and Dollars
Develop Low-Cost Detection and Monitoring Sensors/ Systems (for motion and other modes) ◆◆◆◆	• Key nodes/vulnerability: – Compressors – LNG facilities LPG – High-volume points – Pipeline hubs – Interconnects – Low cost means low cost – Nodal assessment – Mobility • Long-term use	• Low-cost tools/methods for zonation/by-pass • Standard product (so many points to cover); need standard engineering specifications • As costs go down: Satellite-based approaches and others • Blast-resistant materials – but costs?	• Know what is available; what it costs • Tech approach must augment/replace guns/guard and show low cost	• Industry: – Capability-specific • Coordination: INGAA and other (objective of shared recovery) • Regulatory push • Driven by states and others	• Now if not sooner
Energy Assurance: Develop Tools to Forecast/Integrate Current and New Customer Demand (to guide system development/perf) ◆◆◆◆◆◆◆◆	• Integrated gas control (across individual companies and systems) • Example requirement: a 1 MW peaker on line in 15 minutes • Systems include storage	• Real-time assessment and modeling	• New load characteristics • Potential for large, rapid swings • Load-change stresses on pipe/equipment	• DOE lead: details to follow • Industry leads operational aspects • NERC	• Note: activities already underway in DOE; do not duplicate

APPENDIX **A**

PARTICIPANT LIST: ROADMAP UPDATE FOR NATURAL GAS INFRASTRUCTURE RELIABILITY

Rodney Anderson
U.S. Department of Energy
National Energy Technology Laboratory
P.O. Box 880
Morgantown, WV 26507-0880
Phone: 304/285-4709
Fax: 304/285-4403
E-mail: rodney.anderson@netl.doe.gov

Jeffrey L. Barger
Dominion Transmission, Inc.
445 West Main Street
Clarksburg, WV 26301
Phone: 304/627-3910
Fax: 304/627-3323
E-mail: Jeffrey_L._Barger@dom.com

Robert L. Bass
Southwest Research Institute
P.O. Drawer 28510
San Antonio, TX 78228-0510
Phone: 210/522-2326
Fax: 210/681-9661
E-mail: robert.bass@swri.org

John Bayko
Enbridge Consumers Gas
500 Consumers Road
P.O. Box 650
Scarborough Ontario, M1K 5E3
Canada
Phone: 416/495-6185
Fax: 416/495-6163
E-mail: john.bayko@cgc.enbridge.com

Richard Benson
Los Alamos National Laboratory
P.O. Box 1663
Mailstop C331
Los Alamos, NM 87545
Phone: 505/665-3847
Fax: 505/667-0603
E-mail: rabenson@lanl.gov

Lawrence Borski
Williams Gas Pipeline
2800 Post Oak Blvd.
P.O. Box 1396
Houston, TX 77251-1396
Phone: 713/439-2183
Fax: 713/439-4551
E-mail: larry.w.borski@tgpl.twc.com

Terry Boss
INGAA
10 G Street, N.E.
Suite 700
Washington, DC 20002
Phone: 202/216-5930
Fax: 202/216-0876
E-mail: tboss@ingaa.org

Bruce Campbell
Gas Technology Institute
1700 South Mount Prospect Road
Des Plaines, IL 60018
Phone: 847/768-0735
Fax: 847/768-0569
E-mail: bruce.campbell@gastechnology.com

Jim Carey
Energetics, Incorporated
7164 Gateway Drive
Suite 100
Columbia, MD 21046
Phone: 410/953-6227
Fax: 410/290-0377
E-mail: jcarey@energetics.com

Armando Carmona
City Public Service of San Antonio
145 Navarro
San Antonio, TX 78205
Phone: 210/353-2648
Fax: 210/353-2072
E-mail: acarmona@cps-satx.com

Sam Clowney
EL PASO Corp.
Phone: 713/829-2807
Fax: 832/676-1758
E-mail: sam.clowney@elpaso.com

Robert Cupina
Federal Energy Regulatory Commission (FERC)
888 First Street, N.E.
Washington, DC 20426
Phone: 202/219-2700
Fax: 202/219-0205
E-mail: robert.cupina@ferc.fed.us

Daphne D'Zurko
New York Gas Group
1515 Broadway
43rd Floor
New York, NY 10036
Phone: 212/354-4790 x214
Fax: 212/764-7014
E-mail: dzurkodaphne@cs.com

Alicia R. Dalton
Energetics, Inc.
2414 Cranberry Square
Morgantown, WV 26508
Phone: 304/594-1450 ext. 14
Fax: 304/594-1485
E-mail: alicia.dalton@en.netl.doe.gov

David Damon
Dominion Resources / Dominion Peoples
1201 Pitt Street
Pittsburgh, PA 15221
Phone: 412/244-2604
Fax: 412/244-2546
E-mail: david_damon@dom.com

Daniel J. Driscoll
U.S. Department of Energy
National Energy Technology Laboratory
3610 Collins Ferry Road
P.O. Box 880
Morgantown, WV 26507-0880
Phone: 304/285-4717
Fax: 304/285-4403
E-mail: daniel.driscoll@netl.doe.gov

Shari Dunn-Norman
University of Missouri-Rolla
129 McNutt Hall
Rolla, MO 65409
Phone: 573/341-4840
Fax: 573/341-6935
E-mail: caolila@umr.edu

Jack Eisenhauer
Energetics, Incorporated
7164 Gateway Drive
Columbia, MD 21046
Phone:
Fax:
E-mail: jeisenhauer@energetics.com

Gary L. Forman
NiSource Pipeline & Production Group
P.O. Box 1273
Charleston, WV 25325
Phone: 304/357-3095
Fax: 304/357-3618
E-mail: gforman@nisource.com

Christopher J. Freitas
U.S. Department of Energy
Office of Fossil Energy
1000 Independence Ave., SW, MS 3E-028
Washington, DC 20585
Phone: 202/586-1657
Fax: 202/586-6221
E-mail: christopher.freitas@hq.doe.gov

Steven W. Gauthier
Gas Technology Institute
1700 South Mount Prospect Road
Des Plaines, IL 60018
Phone: 847/768-0805
Fax: 847/768-0569
E-mail: steve.gauthier@gastechnology.org

Paul P. Gustilo
American Gas Association
400 North Capitol Street, N.W.
Washington, DC 20001
Phone: 202/824-7335
Fax: 202/824-7082
E-mail: pgustilo@aga.org

Thomas H. Hancock
Tennessee Valley Authority
1101 Market Street
MR 5K
Chattanooga, TN 37402-2801
Phone: 423/751-3900
Fax: 423/751-4442
E-mail: thhancock@tva.gov

Rondle E. Harp
U.S. Department of Energy
National Energy Technology Laboratory
P.O. Box 880, MS CO3
Morgantown, WV 26507-0880
Phone: 304/285-5436
Fax: 304/285-4403
E-mail: rharp@netl.doe.gov

David L. Johnson
Enron Corp.
ECN 4617
P.O. Box 1188
Houston, TX 77251-1188
Phone: 713/646-7885
Fax: 713/646-7130
E-mail: david.l.johnson@enron.com

Walter Kasperczyk
National Fuel Gas Supply Corp
365 Mineral Spring Road
Buffalo, NY 14210
Phone: 716/827-2300
Fax: 716/827-2240
E-mail: kasperczykw@natfuel.com

Julianne Klara
U.S. Department of Energy
National Energy Technology Laboratory
P.O. Box 10940, MS 920L
Pittsburgh, PA 15236-0940
Phone: 412/386-6089
Fax: 412/386-6195
E-mail: jklara@netl.doe.gov

Ibrahim Konuk
Geological Survey of Canada
601 Booth Street
Ottawa Ontario, Canada KIA 0E8
Phone: 613/992-1952
Fax: 613/992-0190
E-mail: ikonuk@nrcan.gc.ca

Thomas (Tom) Kraft
Wisconsin Electric/Wisconsin Gas
1251 W. Main Street
Sun Praire, WI 53590
Phone: 608/825-4023
Fax: 608/825-4012
E-mail: thomas.kraft@wisenergy.com

R. Earl Lewis, Jr.
BGE
1112 Runnymede Lane
Bel Air, MD 21014
Phone: 443/243-1080
Fax: 410/291-5199
E-mail: r.earl.lewis@bge.com

Shreekant B. Malvadkar
U.S. Department of Energy
National Energy Technology Laboratory
P.O. Box 880
Morgantown, WV 26507
Phone: 304/285-4621
Fax: 304/285-1301
E-mail: malvadka@netl.doe.gov

Graham Midgley
Heath Consultants Incorporated
9030 Monroe Road
Houston, TX 77061
Phone: 713/844-1301
Fax: 713/844-1309
E-mail: g.midgley@heathus.com

Robert Al Moody
CMS Energy
5444 Westheimer Road
Houston, TX 77056-5306
Phone: 713/989-7466
Fax: 713/989-1188
E-mail: ramoody@cmsenergy.com

Kevin Moore
Energetics, Incorporated
2414 Cranberry Square
Morgantown, WV 26508
Phone: 304/594-1450
Fax: 304/594-1485
E-mail: kevin.moore@en.netl.doe.gov

Randy L. Moss
Southern Cross Corp.
P.O. Box 2168
Norcross, GA 30091-2168
Phone: 770/441-0403
Fax: 770/368-8014
E-mail: randymoss@mindspring.com

J. Bruce Nestleroth
Battelle
505 King Avenue
Columbus, OH 43201
Phone: 614/424-3181
Fax: 614/424-3181
E-mail: nestlero@bettelle.org

Robert O'Connor
Equitable Resources
1 Oxford Center
Suite 3300
Pittsburgh, PA 15219
Phone: 412/553-5880
Fax: 412/553-7781
E-mail: roconnor@eqt.com

Gerald Paulus
City Of Mesa
640 N. Mesa Drive
P.O. Box 1466
Mesa, AZ 85211-1466
Phone: 480/644-2872
Fax: 480/644-3336
E-mail: gerald_paulus@ci.mesa.az.us

George Ragula
Public Service Electric & Gas Company
80 Park Plaza
T12
Newark, NJ 07102-4194
Phone: 973/430-8561
Fax: 973/643-0978
E-mail: george.ragula@pseg.com

Mark C. Ringwelski
Enron Transportation Services
1400 Smith St.
Houston, TX 77002
Phone: 713/875-1869
Fax: 713/646-8838
E-mail: mark.ringwelski@enron.com

Geoff Rogers
Duke Energy
5400 Westheimer Court
Houston, TX 77056
Phone: 713/627-6396
Fax: 713/627-6350
E-mail: gbroger@duke-energy.com

Christina Sames
U.S. DOT/RSPA
Office of Pipeline Supply
400 7th Street, S.W.
Room 7128
Washington, DC 20590
Phone: 202/366-4561
Fax: 202/493-2311
E-mail: Christina.Sames@rspa.dot.gov

Anthony J. Savino
KeySpan Energy
1650 Islip Avenue
Brentwood, NY 11717
Phone: 917/559-0890
Fax: 631/348-6428
E-mail: asavino@keyspanenergy.com

Hagen Schempf
Carnegie Mellon University
CMU Robotics Institute
5000 Forbes Avenue
Pittsburgh, PA 15213
Phone: 412/268-2000
Fax:
E-mail: hagan+@cmu.edu

Nancy Schultz
Williams Gas Pipeline
P.O. Box 1396
Houston, TX 77251
Phone: 713/215-2888
Fax: 713/215-2325
E-mail: nancy.w.schultz@williams.com

Crystal Sharp
U.S. Department of Energy
National Energy Technology Laboratory
P.O. Box 880
Morgantown, WV 26507-0880
Phone: 304/285-4442
Fax: 304/285-4683
E-mail: csharp@netl.doe.gov

Westley A. Soyster
Equitable Gas
200 Allegheny Center Mall
Pittsburgh, PA 15212
Phone: 412/395-3381
Fax: 412/395-3509
E-mail: wsoyster@eqt.com

Andrew F. Theodos
Columbia Gas Transmission
1700 MacCorkle Avenue, S.E.
Charleston, WV 25325
Phone: 304/357-2365
Fax: 304/357-3585
E-mail: atheodos@nisource.com

Robert Torbin
Foster-Miller, Inc.
350 Second Avenue
Waltham, MA 02451
Phone: 781/684-4369
Fax: 781/890-3489
E-mail: btorbin@foster-miller.com

Ray A. Ward
Memphis Light, Gas and Water
220 South Main Street
Memphis, TN 38101
Phone: 901/320-1062
Fax: 901/320-1597
E-mail: rward@mlgw.org

Cynthia L. Wilson
WV Public Service Commission
P.O. Box 812
Charleston, WV 25323
Phone: 304/340-0302
Fax: 304/340-3758
E-mail: cwilson@psc.state.wv.us

Albert B. Yost II
U.S. Department of Energy
National Energy Technology Laboratory
3610 Collins Ferry Road
Morgantown, WV 26507-0880
Phone: 304/285-4479
Fax: 304/285-4469
E-mail: albert.yost@netl.doe.gov